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SUMMARY TECHNICAL REPORT

OF THE

NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REPORT OF THE TROPICAL DETERIORATION ADMINISTRATIVE COMMITTEE, NDRC

VOLUME I

TROPICAL DETERIORATION OF EQUIPMENT AND MATERIALS

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

TROPICAL DETERIORATION ADMINISTRATIVE COMMITTEE
G. J. ESSELEN, CHAIRMAN

WASHINGTON, D. C., 1946

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A—Armor and Ordnance
Division B—Bombs, Fuels, Gases, & Chemical Problems
Division C—Communication and Transportation
Division D—Detection, Controls, and Instruments
Division E—Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1—Ballistic Research
Division 2—Effects of Impact and Explosion
Division 3—Rocket Ordnance
Division 4—Ordnance Accessories
Division 5—New Missiles
Division 6—Sub-Surface Warfare
Division 7—Fire Control
Division 8—Explosives
Division 9—Chemistry
Division 10—Absorbents and Aerosols
Division 11—Chemical Engineering
Division 12—Transportation
Division 13—Electrical Communication
Division 14—Radar
Division 15—Radio Coordination
Division 16—Optics and Camouflage
Division 17—Physics
Division 18—War Metallurgy
Division 19—Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As EVENTS of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

The size of the Tropical Deterioration Administrative Committee, one of the smallest of the NDRC groups, constituted no measure of its importance or accomplishments. The value of the Committee's work extends beyond the war into the peace. Under the chairmanship of Gustavus J. Esselen, the members of the Committee opened up a new field of knowledge when they undertook a program of fundamental research on the deterioration, under tropical conditions, of equipment and supplies—particularly lenses and other components of cameras and optical instruments, films, textiles, resins, and plastics.

Though the end of the war found the Committee's studies still incomplete, many significant preliminary results had been obtained, extensive collections of fungi and bacteria broadened our knowledge of the relationships of these organisms to deterioration processes, and effective applications of fungicides and protective methods had been developed. An indication of the importance attached by the Armed Services to the work is the fact that six of the projects undertaken by the Committee are being continued by the Army and Navy.

The Summary Technical Report of the Committee has been prepared under the direction of the Chairman and has been authorized by him for publication. This report is a record of enterprise and vision in investigating a hitherto unexplored field of research, and of work in laying a foundation of fact for future development. For the Committee's achievements, we express our deep gratitude.

VANNEVAR BUSH, Director
Office of Scientific Research and Development

J. B. CONANT, Chairman
National Defense Research Committee

FOREWORD

The prime objectives of the Army and Navy in requesting the NDRC to undertake a project on the prevention of tropical deterioration were to effect coordination between the individual programs of the military agencies and to arrange for additional studies which were needed. Since the primary purpose of this report is to summarize the technical accomplishments in the studies which were undertaken, attention is given in this foreword to the background for the administrative organization which was primarily responsible for the successes in coordinating individual and separate investigations.

In February 1944, a conference was held attended by 101 Army and Navy officers and OSRD representatives. Inasmuch as large scale activities in tropical regions had presented a serious problem in the loss of equipment through tropical deterioration and an even more serious problem in the unserviceability of equipment needed for use, the conference was held in order that various interests in the problem might be stated and in order to consider an organization through which coordination of all investigations on the problem could be realized.

To effect coordination and guide all the interrelationships of studies pertinent to the problem it was proposed that there be established a Joint Army-Navy-NDRC Tropical Deterioration Steering Committee, consisting of three members each from the Army, Navy, and the NDRC. This proposal was formally presented with a Project Request for Army-Navy Project 14. During most of its activity, the following were members of the Tropical Deterioration Steering Committee: For the Army: Lt. Col. Don Brouse, Colonel W. J. Reich, and Major F. P. Willcox; for the Navy: Lt. Commander H. W. Gilbert, Commander A. E. MacGee and Captain R. O. Phillips; for the NDRC: Theodore Dunham, Jr., Selman A. Waksman, and Gustavus J. Esselen, Chairman.

The Tropical Deterioration Administrative Committee, having the usual administrative and technical functions of an NDRC division, was established on the recommendation of the Steering Committee to arrange for various contracts which were needed and to supervise their contract activities. Subsequently, subcommittees of the Administrative Committee were organized to insure that important problems presented in various broad fields would be covered. Subcommittees were appointed as follows: Coordination of Test Methods; Packaging; Electrical and Electronic Equipment; Textiles and Cordage; Optical Instruments; Synthetic Resins, Plastics and Plasticizers; and Photographic Equipment and Supplies. In addition to OSRD appointees, Army and Navy personnel served as members of most of the subcommittees. The Service personnel were chosen from Service branches having direct interests in the particular subjects.

The results of the various research projects which were recommended to round out the tropical deterioration program are summarized in this report. However, a major activity of the Tropical Deterioration Administrative Committee—the distribution of information on tropical deterioration—is not reviewed. For this purpose, there was established the Tropical Deterioration Information Center. All available reports, both foreign and domestic, related to tropical deterioration were deposited there and abstracts of these were published in the semi-monthly Tropical Deterioration Bulletin. From time to time additional reports on special subjects were also prepared and distributed. These various publications of the Information Center were distributed to a regular mailing list of over 250 Army and Navy officers and laboratories, and Allied laboratories.

Direct Service liaison was accomplished through a rather large list of appointed liaison officers. In addition to the distribution of reports and meeting minutes to these liaison officers, special meetings were held with them to review the progress which had been made in the various studies and to obtain the viewpoints of the various branches of the Services toward the problems at hand. Needless to say, the Service members of the subcommittees fulfilled an important liaison function with many branches of the Army and Navy. In this regard, the publications of the Information Center were particularly effective in that they served to keep all Service groups informed of current progress in the field.

The investigations on optical instruments which are reported were initiated during 1941 and 1942 by Section 16.1 of the NDRC under Project OD-13. These studies were transferred to the Tropical Deterioration Administrative Committee shortly after it was organized. While the project was under the auspices of Section 16.1 methods were developed for the protection of optical instruments by the use of volatile and contact fungicides and the Panama Test Station was

established. Since the transfer of this work, further studies of optical instruments have been made, particularly long time field exposures and research on improved sealing compounds. The program of the Panama Test Station has been extended to include, in addition to studies on optical instruments, exposure tests on a wide variety of other materials.

The Japanese surrender found the different contract activities in various stages of completion, but they were deemed of sufficient importance by the Army and Navy that six of the seven active contracts at that time were continued by interested Service branches.

The significance and importance to the Armed Services of our coordinated program is indicated by the fact that in accordance with a recommendation of the Tropical Deterioration Steering Committee, there has been established a Joint Army-Navy Committee having official standing to coordinate investigations on tropical deterioration and the prevention thereof.

The success of our program was due in a large measure to the fine cooperation which was shown by all those who participated in the work. The members of the Steering Committee, both individually and collectively, deserve recognition for the valuable services which they rendered. The expert services of the members of the Administrative Committee and the Subcommittee Chairmen are also acknowledged. Major credit for the accomplishments in research studies and contract activities is given to Dr. Elso S. Barghoorn, Jr., Office of Field Service; Dr. W. G. Hutchinson, University of Pennsylvania; Dr. William H. Weston, Harvard University; Dr. Glenn A. Greathouse, The George Washington University; Dr. Herbert W. Reuszer, Soil Conservation Service, U. S. Department of Agriculture; Mr. H. F. Robertson, Bakelite Corporation; Dr. Ralph K. Witt, The Johns Hopkins University; and Dr. R. H. Emee, Rensselaer Polytechnic Institute. The interest and assistance of Mr. N. A. Whiffen and Dr. M. F. Day, Australian Scientific Research Liaison Office and of Mr. B. N. P. Hutchesson, British Commonwealth Scientific Office, in matters concerning Australian, Canadian, and United Kingdom studies is also greatly appreciated.

Special appreciation is extended to Dr. Charles Heimsch, Technical Aide and Lt. Wesley H. Suit, USNR, Special Assistant to the Chairmen for their unusually fine services in handling the many administrative and technical details connected with the work of this Committee.

GUSTAVUS J. ESSELEN
Chairman, Tropical Deterioration
Administrative Committee

PREFACE

THIS REPORT presented in this volume summarizes the technical accomplishments in the studies which were undertaken by the Tropical Deterioration Administrative Committee. No attempt has been made to discuss the important aspects of the Committee's work relative to the distribution of information to the branches of the Army and Navy which were concerned with tropical deterioration problems. This constituted an important aspect of the Committee's program to coordinate investigations on the problems of tropical deterioration conducted by the individual branches of the Army and Navy.

The status of tropical deterioration problems as they pertain to specific types of materials has previously been summarized in a number of reports which have been issued by the Tropical Deterioration Administrative Committee. The classes of materials for which such reports have appeared are as follows: Optical instruments; textiles; synthetic resins, plastics and plasticizers; and, photographic equipment and supplies. In addition to these, a report has also appeared which summarizes and evaluates the various test methods which have proved to be useful in determining the suitability of materials for tropical service. These reports have served as the primary basis and background for certain of the chapters in this volume; for instance, Chapter 5 is an abridged version, as approved for publication, and which appeared in the April 1946 issue of *Modern Plastics*, of a report of the Committee which discusses the problems of fungal growth on synthetic resins, plastics, and plasticizers. Also, Chapter 6 is almost entirely based on the report which summarizes the activities of the Subcommittee on Photographic Equipment and Supplies. Those discussions which are not based on previous summary reports are organized either to relate studies which have been reported independently or to give emphasis to information which has been only recently reported.

A considerable number of reports on tropical deterioration studies have appeared from Army and Navy Laboratories as well as from the Allied Governments of Australia, Canada, and the United Kingdom, and no attempt has been made to summarize or to include as bibliographic entries all of those which were in any way related to the studies of the Tropical Deterioration Administrative Committee. However, reference is made to certain of these reports which bear particular relation to the studies reported in this volume.

In presenting this summary of the investigations of the Tropical Deterioration Administrative Committee, a highly technical background on the part of the reader is not presupposed. The aim and objective of the Committee's program and the results which were achieved should be clear to all who are aware of the problems which tropical use imposes upon the serviceability of equipment and supplies. For detailed information and results of the investigations which have been made, the reader is referred to the various reports which are included as bibliographic entries.

Acknowledgment is made to all the investigators who are responsible for the studies reported here for their ideas and information which have been drawn upon freely. Their experience and broad acquaintance with the problems at hand have been a valuable contribution to this report.

CHARLES HEIMSCH
Editor

CONTENTS

SUMMARY

With the Service request for the project on the prevention of tropical deterioration of equipment and supplies, it was recommended that there be established a joint Army-Navy-NDRC Tropical Deterioration Steering Committee to coordinate investigations on the subject which were then underway and to arrange for new investigations as they were needed. Later, upon the recommendation of the Steering Committee, there was organized by the OSRD the Tropical Deterioration Administrative Committee [TDAC], having the usual administrative and technical functions of an NDRC division, to arrange for various contracts which were needed and to supervise the contract activities. The studies which are reported herein are those which were under the supervision of the Administrative Committee.

In tropical warfare, equipment and supplies are usually exposed to heavy rainfall and high relative humidity which together introduce numerous problems relative to the performance and serviceability of materials, whereas these problems are of little or no concern in temperate regions. Tropical climatic factors are important in themselves in that most items of equipment and supplies which are not protected against them are subject to severe damage; but they are also important in that they furnish ideal conditions for the growth and development of microorganisms (fungi, actinomycetes, and bacteria). The importance of these microorganisms lies in the fact that collectively they are able to attack a wide range of basic materials and thus cause the destruction or deterioration, total or partial, of military items.

The importance of microorganisms in the tropical deterioration of military items was established in field studies conducted by the Australians during the early stages of the Pacific phase of World War II. However, this early information and that which continued to become available later tended to emphasize the nature and extent of damage to materials rather than the fundamental reasons for the damage or how it occurred. Early in the program of TDAC, plans were initiated for a Science Mission to Pacific areas to obtain fundamental information on the causes of tropical deterioration with emphasis on determining the role of microorganisms and the mechanism by which damage is done, including the sequence of changes where more than one organism is involved. Additional studies related to these were also planned. It was necessary, after final arrangements for departure were made, to cancel these plans; however, it was arranged for a modified program to be undertaken in Panama.

In this report there are reviewed the activities of the Tropical Fungus Culture Collection [TFCC], which was organized to receive, maintain, and identify the fungi associated with deterioration isolated in the course of these Panama studies. The major source of these organisms was an extensive set of experimentally treated textile samples which were studied intensively with respect to the influence of physical and biological factors in the deterioration process. After fungus cultures were received from Panama, they were purified, when necessary, and their identity was determined in order to provide significant information for analysis and correlation with other studies. Fungi were also isolated in Panama from natural sources, such as decaying plant remains, etc., in order to understand fully the origin and distribution of the forms important in textile deterioration. Textile materials which had been sterilized were also subjected to attack by fungi under natural conditions in order to differentiate between those fungi derived from local sources (Panama) and those fungi which might have been present on the experimental panels before and during shipment.

In all, approximately 4,500 fungus cultures were deposited in the Tropical Fungus Culture Collection. As stated above, these were derived for the most part from the Panama field studies. Fungi present in the collection other than those from Panama were obtained primarily from the Australian Mycological Panel, which supplied a set of the most important organisms isolated in New Guinea field studies, and various Army and Navy laboratories engaged in tropical deterioration studies.

The task of maintaining such a large collection of living fungi was one of tremendous proportions. At any given time a majority of the cultures were kept in an actively growing condition. For purposes of long-time storage, however, cultures were preserved in a dormant condition by a lyophilization process. This consists of freezing instantaneously a small quantity of fungus spores suspended in horse serum or skim milk in small glass tubes, after which the spore suspension is dried by pumping off water vapor under vacuum until a dry pellet is formed. While under

vacuum the glass tubing is fused off and the container with pellet is hermetically sealed. This method of preservation is relatively new, but it is known that fungi will survive at least five years storage under these conditions. The use of this method by TFCC represented the first attempt to apply it in such an extensive fashion to such a wide range of different fungi. Many cultures which were not adaptable to preservation by this technique for a variety of reasons were successfully conserved in a dormant condition by covering the active cultures with sterile mineral oil.

By the application of these methods for a long-time storage, this extensive collection of fungi has been preserved for future study. Without doubt it represents the largest collection of tropical fungi which has ever been assembled in the living condition and the full potentialities of these organisms still remain to be exploited. There is every reason to believe that upon intensive study these forms will yield information which will be valuable to agriculture, medicine, and other fields of science.

Although efforts were concentrated on maintaining and identifying the fungi in the collection, certain important observations on their growth and behavior were possible. An analysis of the cultures indicates those forms which are most important in textile deterioration in Panama, permits comparison with those fungi which have been reported as significant in textile deterioration in Panama, and permits comparison with those fungi which have been reported as significant in textile deterioration in other geographical locations. It has been possible to compare the Panama fungi with collections from Florida, India, and New Guinea and other Pacific regions. The significance of agreement or disagreement in these comparisons can only be determined by future detailed analyses involving precise comparative studies.

In conjunction with the Panama field studies on deterioration of textiles by fungi, studies were also conducted to determine the extent to which these materials were attacked by bacteria under natural conditions. The bacteria which were obtained in these studies served as the nucleus for a Bacteria Culture Collection [BCC] maintained by TDAC. To these bacteria cultures from Panama were added many cultures isolated by Quartermaster laboratories in studies of deteriorated materials returned primarily from Pacific areas. The total number of bacteria cultures on hand was approximately 1,100.

For practical purposes, the bacteria were classified into two main types according to their physiological capacities and effects on the deterioration of fabrics: (1) those capable of destroying cellulose, and (2) those incapable of destroying cellulose. Only limited specific identifications were able to be made in each group.

The significance which cellulose decomposing bacteria may hold in the deterioration of fabrics is obvious, and in the Panama field studies these forms were present in large numbers on fabrics which showed marked evidence of deterioration. Noncellulose decomposing bacteria were present on experimental fabrics after four to six weeks of air exposure in such large numbers that it seems they may play an important part in the initial stage of deterioration of treated fabrics. It is suggested that these noncellulose decomposing bacteria may cause destruction of the treating agents which are applied to fabrics, thus causing a reduction in fungicidal value and possibly increasing chemical deterioration of the fabric. Additional studies are necessary before this problem can be further clarified.

In addition to the information on the biological deterioration of textiles which resulted from the Panama field studies, valuable data on other aspects of the performance of textiles in the tropics were also obtained. It was possible to determine the efficacy of the various experimental fungicides under different conditions of exposure and to relate their performance to the physical factors of the environment. The observation that sun exposure promotes chemical deterioration of fabrics by causing a breakdown of certain fungicides is important, particularly in that copper naphthenate, the fungicide most widely used on tentage and tarpaulins, was among those most seriously affected when it is not adequately protected from sunlight by screening pigments. Evidence was also obtained that certain ingredients of the water repellent finish, such as aluminum acetate, when applied to heavy fabrics were subject to the effects of sunlight with subsequent photochemical deterioration of the fabric.

The deterioration of optical instruments in tropical service was among the problems which proved to be serious in early Pacific operations. Deterioration of optical instruments may be due to moisture alone or moisture in combination with fungus. Many materials ordinarily used in optical instruments are capable of supporting fungus growth; furthermore, organic debris such as a dead insect or even a fingerprint can furnish nutrients which will support sufficient fungus growth

to be troublesome and decrease the efficiency of an instrument. If actively growing fungi are allowed to persist within an instrument for extended periods, permanent damage to lenses, prisms, and other parts can result.

The construction of many optical instruments, particularly old models, many of which were necessarily used, is such that moisture readily gains access to the interiors of the instruments with fluctuations in temperature and resulting changes in air pressure. In addition to the direct effects of the moisture within instruments, it provides relative humidities adequate for the growth of fungi. Prevention of moisture deterioration can only be achieved by virtually complete sealing of all cracks and openings.

An adequate method for controlling fungus growth within optical instruments was developed. In field trials under drastic jungle conditions in Panama this method has kept binoculars free from fungi for over 21 months. This method consists of applying a mixture of 50 per cent of the fungicide Cresatin (metacresyl acetate) and 50 per cent ethyl cellulose enclosed in a small aluminum capsule with minute openings. The capsule is attached with cement within the instrument out of the paths of light rays. The fungicide is volatile and the small openings allow only gradual escape of the fungicide from the reservoir within the capsule.

Another method using a contact fungicide, Thanite (fenchyl thiocyanoacetate), rather than a volatile fungicide for the control of fungi in optical instruments is also described.

With the importance which was given to proper sealing of instruments and the knowledge that the compound which was most widely used was not entirely satisfactory, a search was made for a more suitable substitute. The most promising of the experimental compounds which were tried had as their basic ingredient a proprietary thermoplastic resin of an undisclosed formulation.

This report also reviews the problem of fungal growth on synthetic resins, plastics, and plasticizers and discusses the problem with reference to the susceptibility of pure resins to fungal attack, the susceptibility of plasticizers and other plastic components to fungal attack, the susceptibility of complete plastic compositions to fungal attack, the effect of fungal growth on properties of plastics, and the results of experiments in which fungicides had been added to plastics. Practically no information on the tropical deterioration of plastics existed prior to World War II, and investigations were organized by TDAC to broaden and increase knowledge of the performance of plastics under tropical conditions. The results of these investigations are cited in the review of the general problem. An important question on which further information is necessary before the problem can be fully solved concerns the precise effect of fungus growth on plastic materials. It is well established that surface growth on plastics used in electric and electronic equipment is deleterious in that it affects the electrical properties of the plastics. However, the effect of fungus growth on the physical and mechanical properties of plastics requires further elucidation.

Much attention was devoted to the tropical deterioration of photographic equipment and supplies. The recommendations to prevent the deterioration of films, chemicals, and cameras and accessories are reviewed. With these items, particularly film, proper packaging for tropical service is an essential. The problem of fungus attack of processed films was thoroughly investigated. The importance of the problem rests in the fact that negatives, which serve as important historical records of units, campaigns, etc., as well as individual medical records, are highly subject to fungus attack inasmuch as the gelatin emulsion is an excellent nutrient for fungus. A fungicidal treatment which can be applied to processed films in a dip bath was developed and this method shows excellent promise over various other methods which were tried. Investigations revealed that cautious use of lacquers containing the mercurial fungicide Merthiolate is effective in controlling fungus growth on camera parts. Cautious use of such lacquers is indicated because fungicides containing mercury have been shown to have an adverse effect on photographic emulsions. Innovations in design of cameras so as to permit ready interchange and serviceability of parts would markedly decrease the incidence of tropical deterioration in these items, particularly when accompanied by adequate tropical storage facilities and a proper maintenance program.

The tropical deterioration of electric and electronic equipment presented many problems. In achieving a solution to these, the adverse effect of moisture and fungus on components and parts of such equipment requires control. The fundamental studies of TDAC relating to these problems are summarized. Many questions and problems arose concerning the use of fungicidal lacquers and varnishes as a moisture barrier and as a protection against fungus on such equip-

ment. As the result of a Service request to settle some of these points of conflict, investigations to determine the effects of fungus growth on hookup wire were organized. Closely related studies on the long-range effects of moisture and fungus on electric insulating materials were also undertaken. A survey of existing information indicated that considerable data were available on the effects of moisture on electric insulating materials after exposure for short periods, but little or no information was available on the performance of such materials in exposures of long duration nor were the results related to effects of fungi. It is expected that with separate evaluation of the effects of moisture and fungus upon various types of plastics used as insulating materials, the information will permit a more realistic interpretation of the performance of these materials under tropical conditions, and furnish a working basis for selection of high-quality materials in design of new equipment for tropical service.

The investigations on the coordination of test methods which are summarized were undertaken by TDAC because there was no uniformity or general agreement as to test methods for evaluating the suitability of materials for tropical service, and it was often impossible to duplicate test results in different laboratories. It was, therefore, obviously a prime essential to develop standard conditions for tests, which could be agreed upon by all laboratories and thus permit duplication of results on a given sample regardless of the laboratory in which it was tested. Investigations were conducted to determine suitable test methods for hookup wires, coating materials, such as lacquers and varnishes, and plastics. As a result of these investigations, test methods were recommended for standard use in evaluating the fungus resistance of these materials. Extensive studies were also conducted on certain aspects of textile testing using pure cultures of test fungi. Detailed investigations were also made of various biological factors in determining the fungus resistance of plastics.

In addition to conducting fundamental studies on various aspects of tropical deterioration problems, TDAC organized and carried out an extensive program of testing materials for the Army and Navy under natural tropical conditions in Panama and under simulated tropical conditions in a tropical house at the University of Pennsylvania. The materials exposed in Panama numbered over 15,000 individual items, and the materials exposed at the University of Pennsylvania numbered over 1,309 individual items.

Recommendations concerning problems which are still in need of investigation are given for the following materials: textiles and cordage; electric and electronic equipment; synthetic resins, plastics, and plasticizers; and photographic equipment and supplies. These recommendations were proposed by the several subcommittees which study the problems for each of the above classes of materials.

At the time of the Japanese surrender, valuable preliminary results had been obtained from the studies of TDAC which were in progress, but none of the studies had reached the stage at which they could be considered as complete. It is gratifying to report that six of the seven projects which were underway at the close of hostilities were deemed of sufficient importance to warrant their continuation by various groups of the Armed Services. The significance and importance to the Armed Services of the coordinated program which was organized during World War II is indicated by the fact that in accordance with a recommendation presented to the Army and Navy, there has been established a joint Army-Navy Committee to coordinate investigations on tropical deterioration and the prevention thereof.

Chapter 1

INTRODUCTION

1.1 PROBLEMS PRESENTED BY TROPICAL WARFARE

When military operations are conducted in tropical regions, equipment and supplies are subjected to climatic conditions far different from those of temperate regions. The heavy rainfall of many tropical areas and the continuously high relative humidity of most tropical areas introduce numerous considerations and problems relative to the performance and serviceability of materials in tropical warfare whereas these considerations and problems are of little or no concern in temperate regions. Tropical warfare demands that most items of matériel be adequately protected against the effects of moisture. This protection is necessary not only while items are in use, but also during the preceding period of transit and storage. Most items of equipment and supplies which are not protected against the effects of moisture are subject to severe damage.

Not only are tropical climatic factors important in themselves, but it is perhaps even more significant that they furnish almost ideal conditions for the growth and development of microorganisms. Included among the microorganisms important in this respect are the thousands of forms of fungi, actinomycetes, and bacteria. The importance of these various microorganisms lies in the fact that collectively they are able to attack a wide range of basic materials and thus cause the destruction or deterioration, total or partial, of military items. Furthermore, by virtue of the fact that these microorganisms are able to obtain nourishment from organic debris present on materials such as glass and metals, they are able to grow on these materials and, by their presence, cause serious damage. The damage to lenses and prisms of optical instruments which is discussed in Chapter 3 has been particularly serious.

1.2 EARLY STUDIES BY AUSTRALIAN GOVERNMENT

Studies on the prevention of tropical deterioration of matériel were undertaken by the Australian government in the early stages of the Pacific phase of World War II. These early investigations included field studies in New Guinea by a scientific mission of the Scientific Liaison Bureau.[1] The observations which were made on the performance of stores and equipment under field conditions in New Guinea served as an important source of information for the tropical deterioration program of the military agencies in the United States.

1.3 EARLY STUDIES IN THE UNITED STATES

It is beyond the scope of this report to review the programs of the military agencies which had as their objective the protection of materials against tropical deterioration. It will suffice to point out that by 1944 various branches of the Army and Navy had extensive programs underway. Furthermore, there had resulted from these studies many treatments which were effective in reducing the effects of tropical exposure and thereby extending the service life of equipment.

1.4 STUDIES OF THE TROPICAL DETERIORATION ADMINISTRATIVE COMMITTEE

The studies of the Tropical Deterioration Administrative Committee [TDAC] which are reported here supplemented the individual programs of the branches of the Army and Navy by giving attention to problems upon which information was not available or by providing additional information on studies which were then underway.

All phases of the TDAC investigations are reported in the following chapters. A background for the investigations undertaken is presented with a discussion of each class of material. It will be noted that no consideration is given to the general and important subject of packaging. From the viewpoint of prevention of tropical deterioration, packaging methods are important in that protection against the effects of moisture during periods of transit and storage must be given. Attention was given to these problems by the Subcommittee on Packaging which surveyed this particular subject to determine the extent to which the problem of moisture-resistant packaging was already being investigated. This subcommittee reported

that the preliminary work with a view to develop water-resistant packages had been practically completed by both the Army and Navy, and that it was then largely a matter of putting the resulting recommendations into effect, and the few details which still remained to be handled were being adequately cared for by other agencies. As a result of this report, no investigations on packaging materials or methods were organized.

In the initial organization of the TDAC program, the desirability and advantage of field studies in tropical regions were recognized. Since there was no basis upon which to assume that the climatic and biological factors of all tropical regions were identical, it was apparent that the greatest contribution to the tropical deterioration program could be derived from studies conducted in Pacific regions where equipment and supplies would find greatest use. Such studies were particularly desirable in that precise information of the processes of deterioration was only meager — reports which had been made emphasized the nature and extent of damage rather than the fundamental reasons for the damage or how it occurred. Fundamental information on deterioration processes not only was desirable in order to develop new and more effective preventive treatments, but it could be applied in the development of more refined techniques for evaluating the suitability of materials for use in the tropics.

Plans were initiated for a science mission to Pacific areas with the following objectives.

1. To determine the causes of tropical deterioration with emphasis on determining the role played by microorganisms (molds and bacteria).

2. To determine the mechanism by which the damage is done, including the sequence of the changes where more than one organism is involved.

3. To determine the effectiveness of the fungicides at present in use.

4. To test under field conditions new fungicides selected because of their promise under laboratory conditions. This work would not merely serve to evaluate the new fungicides but would provide a valuable correlation of laboratory tests with similar tests under actual operating conditions.

5. To collect and bring back:
   a. Representative samples of materials showing tropical deterioration.
   b. Cultures, isolated in the field, of biologically active agents in deterioration.
   c. Any samples of enemy equipment which show superior resistance to tropical deterioration.

6. To contact the Australian laboratories, field stations, and other agencies making such investigations in that area and report on the work which they are doing relative to tropical deterioration.

After final arrangements for departure were made, it was necessary to cancel these plans. It was arranged, however, for a modified program to be undertaken in Panama. This consisted primarily of the studies on the deterioration of textiles as summarized in Chapter 4. These Panama studies contributed to a clear understanding of the deterioration process as it affects textiles, and furnished valuable information with respect to the nature and action of the biological agents of deterioration. Had it been possible to conduct these studies in the Pacific, the results would have had even fuller significance. Not infrequently, as the TDAC program developed, important questions were raised which could have been properly answered if there had been available full knowledge of field conditions or how protective treatments of items of equipment performed in the field. There have been many indications that the program of tropical deterioration in this country would have benefited extensively had the proposed mission to the Pacific been allowed to carry on its program.

Chapter 2

ORGANISMS ASSOCIATED WITH TROPICAL DETERIORATION

2.1 INTRODUCTION

Interest and attention was directed to the relationship of fungi to the tropical deterioration of materials because fungi were conspicuous on deteriorated materials in the tropics and knowledge of their characteristics and properties led to the obvious conclusion that they were the causal agents of many forms of deterioration. Australian studies in New Guinea early in World War II emphasized the predominance and importance of fungi in the deterioration of many types of stores.

Fungi are found growing in nature under a wide variety of conditions and their reproductive structures or spores are universally distributed. The soil contains enormous populations of fungi. These soil-inhabiting forms develop airborne spores which inoculate materials, and under proper conditions of moisture and temperature such spores are capable of germination and growth. The majority of fungi which have been shown to be significant in the deterioration of materials are characteristically soil-inhabiting forms.

Fungi, as well as bacteria, in contrast to green plants, comprise a group of organisms which are unable to synthesize the energy yielding organic compounds necessary for their metabolic activities, except for relatively few exceptions, and consequently these compounds must be derived from external sources. By means of enzymes secreted by the organisms, elaborate and insoluble organic substances can be broken down to simple and soluble materials capable of absorption. The different species of fungi and bacteria vary in the limits within which they are able to attack organic substrates, but collectively they can effectively decompose most organic materials. It is by such activity that these organisms deteriorate many materials; in many cases, however, the mere presence of the organisms is undesirable.

For detailed considerations of the structure and physiology of various fungi and bacteria reference can be made to the many textbooks and treatises on the subject. Selected references are given in OSRD Report 6267[1] issued by the Tropical Deterioration Administrative Committee [TDAC]. Many reports prepared on the subject of tropical deterioration have given only cursory treatment to the organisms concerned. The report cited above considers the nature and characteristics of some fungi associated with tropical deterioration in slightly greater detail, and was prepared primarily for the use of Army and Navy laboratories engaged in studies on tropical deterioration.

Fungi are encountered as deteriorative agents in temperate regions as evidenced by molding of foodstuffs, leather goods, and such items as shower curtains, wood, and paint; but, except for the rather widespread damage to crop plants, they are of relatively minor economic significance. With the importance which fungi assumed in tropical deterioration it was necessary to determine whether the tropical forms embraced types different from the more commonly known temperate forms, and if they were the same, whether the tropical forms represented different or more potent physiological strains. As a result of the work undertaken, comparative evaluations can be made and these are discussed in Section 2.2.7. The importance of establishing these points is obvious when it is considered that preventive measures can be applied more intelligently when the exact nature of all deteriorating factors is known.

Prior to the work of TDAC, the significance of bacteria in the deterioration of materials in the tropics was generally disregarded, or if acknowledged, was deemed to be relatively unimportant, except in the destruction of foodstuffs. In the TDAC program, provision was made for field studies on the role of bacteria in the deterioration of fabrics. These were found to play an important role which is discussed in Sections 2.3 and 4.5.

The only investigations concerning insects and other forms of animal life as agents of deterioration were those relative to the part played by mites in the deterioration of optical instruments as discussed in Chapter 3.

2.2 TROPICAL FUNGUS CULTURE COLLECTION

Procedures essential to proper care and maintenance of fungus cultures for intensive study and preservation are such that permanent and well

equipped laboratory facilities are necessary. The Tropical Fungus Culture Collection [TFCC] was established by TDAC at the Biological Laboratories of Harvard University to serve as a place for deposit and maintenance of fungus cultures isolated during field studies of tropical deterioration. In addition to this phase of its activity, TFCC distributed cultures on hand to laboratories of the Army and Navy and other authorized agencies for study or for use as test organisms.

The following discussion pertaining to TFCC is based upon OSRD Report 5681[2] which summarizes the studies which were conducted.

2.2.1 Purpose of the Tropical Fungus Culture Collection

The field studies from which the majority of fungus cultures in the collection were obtained pertained to the deterioration of textiles and these are described in Chapter 4. With reference to these field studies it was intended that the functions of TFCC would be to isolate when necessary, to purify, to identify, and to preserve the fungus cultures related to fabric deterioration. The desirability of having fungi of known potentiality generally available for use as test organisms was recognized, and it was also intended that TFCC would serve as a distribution center for all such cultures which were available.

The phase of the program concerned with the organisms isolated during field studies of textiles paralleled studies by Quartermaster laboratories which involved determining the organisms responsible for the deterioration of textile fabrics (see Section 4.8). One point in contrast, however, is that the cultures which were the subject of the Quartermaster investigations were isolated from materials returned from tropical areas and isolation was made in this country. Because of the relationship and importance to the Quartermaster program, close cooperation with Quartermaster personnel was maintained throughout the period of activity.

The task of purifying, identifying, and particularly maintaining and preserving the fungus cultures was one of immense proportions. The very nature of the ultimate objectives of all phases of the study made it desirable to have as much information as possible on the physiological characteristics of the organisms in order to determine with some exactness the role of the organisms in the deterioration of the test fabrics. Much of this information could be derived from existing knowledge of the organisms once identification was made. Accordingly, studies concerning the identification of the fungi were given first priority. Valuable supplementary information on the properties of many organisms involved in tropical deterioration was derived from physiological studies by the Australian Mycological Panel and laboratories of the Department of Agriculture and those of other TDAC contractors.

The work of TFCC was of such magnitude that it could not be completed by TDAC and it was arranged that this project would be continued by the Office of the Quartermaster General. The collection has continued to occupy an important position in the Quartermaster program concerning textile deterioration.

2.2.2 Organisms in the Collection

The cultures deposited in the collection totaled 4,103; most of these came from the Canal Zone, some from subtropical United States, and a few from Australia. The nature of the cultures and their sources are indicated below.

CULTURES FROM AUSTRALIA

These comprised a small set of 40 cultures furnished by the Mycological Panel of the Scientific Liaison Bureau, Australia, and were derived from their extensive collection isolated from deteriorated materials, chiefly from New Guinea, in the course of field work. These cultures included fungi which were destructive to cellulose and other basic materials as well as to various components of the finishes of textiles and sleeving and insulation of wires. Through intensive study by the Mycological Panel, the potentialities of these cultures were determined as well as their applicability to tests for evaluating the tropic-proofing of a wide variety of items.

CULTURES FROM QUARTERMASTER COLLECTION IN FLORIDA

This set of 1,817 cultures of microorganisms was derived from deteriorated articles which were representative items of equipment exposed in storage dumps under conditions carefully planned to approximate as closely as possible those which had been found to prevail under actual operations in the Pacific. The entire range of conditions encountered was represented in the individual dumps. Fluctuations of temperature and moisture were recorded, the conditions of the

various representative items of equipment were observed, the progress of the deterioration of various articles was noted and from them the molds and other microorganisms were isolated at suitable intervals as the exposure progressed. The purpose of this collection was primarily to gain information as to the identity and significance of the organisms concerned in the deterioration of matériel under field conditions in the subtropical United States where the rigors of climate, to a milder degree, approximate those of the tropics.

CULTURES FROM PANAMA

Textile Exposure. These organisms were derived from the exposure of three sets of experimental textiles. A large majority of the organisms were obtained from the textile exposures described in Chapter 4 which were performed at Barro Colorado Island, Panama. Of the various methods which were used to isolate fungi from these textile samples, the method in which bits of yarn from obviously affected spots were teased out under aseptic conditions was most widely used. This method was found especially helpful in revealing the fungi which were actually growing in the fabric, thus causing its deterioration, and distinguished them from the fungi which were superficial or adventitious on the fabric. In all, about 2,000 cultures were isolated in the course of this work and approximately 75 per cent of them were identified by October 31, 1945.

In another of the textile exposures using the same materials of the initial test, the exposure plan was modified in order to provide more realistic conditions which more closely approximated field use of textiles. When last reported, only about 200 cultures of fungi were received from this test, but when the entire complement is obtained, they should present a highly significant comparison with the original textile exposure test since the samples are exact duplicates. The difference in weather conditions and the difference in exposure, in that periods of exposure were alternated with periods of storage, should give some evidence as to the influence of these additional factors on the deteriorating action of the fungi concerned.

The other textile exposure test from which fungi were isolated was also performed under Quartermaster auspices. The exposure was planned to secure evidence on the influence of the various light-screening compounds, finishes, and fungicides on deterioration. For this an entirely new set of fabrics was prepared and included those which had only preparatory and dyeing treatments with no fungicide, those treated with light-screening compounds with or without selected fungicides in various combinations after preliminary treatment, and those treated with selected fungicides after preliminary treatment. The exposure was varied according to the treatments which were given to the samples. By the end of October 1945 only about 100 cultures of fungi from the samples were received. The identification of fungi from these samples is to be correlated with investigations on the chemical and photochemical degradation of the samples and, when this information is complete, it should contribute materially to an understanding of the influence and complicated interaction of the molds, the fabric, the finish, and the climate in relation to tropical deterioration.

Sterilized Cotton. A large number of cultures were derived from cotton fabrics which were exposed after sterilization by steam under pressure or by the use of disinfectants such as formaldehyde or ethyl alcohol. The purpose of these exposures was to gain evidence as to the identity and the time of development on the sterilized fabrics of mold derived from natural sources in the vicinity. An analysis of these organisms should shed some light on the influence of such sterilization methods on the subsequent development of molds on the samples. By comparison of these fungi with those isolated from comparable unsterilized samples, information relative to the influence of spores picked up in manufacture or transit to the tropics should be clarified.

Natural Molds. These cultures were collected with the purpose of determining the natural sources of fungi which had been found to be most predominant, frequent, or significant on the exposed textiles.

Cultures from Optical Instruments and Miscellaneous Materials Exposed. A total of 231 cultures were obtained from optical instruments and materials other than textiles which were exposed at Barro Colorado Island for TDAC.

CULTURES FROM MISCELLANEOUS SOURCES

In addition to the more extensive and important sets of cultures indicated above, there were received a number of miscellaneous acquisitions mostly in rather small lots sent either for identification, comparison, or study. Most of them were submitted by laboratories of the Army or Navy or of other government agencies.

2.2.3 Cultures Distributed

A total of 1,362 cultures were sent out from the TFCC during the first 14 months of its existence. These cultures fell into three main categories: (1) identified cultures of known potentialities sent to authorized agencies chiefly for use in testing, (2) preliminarily identified cultures sent to specialists in the taxonomy of notoriously difficult genera for final specific identification, and (3) cultures removed for permanent inclusion in other collections, particularly bacteria and yeasts.

The cultures for use in testing were supplied primarily to laboratories of the Army or Navy and were largely those from the Australian Mycological Panel because of their known potentialities and applicability for testing purposes or because of their value as standards of comparison for species in process of identification. In most cases only a few of these cultures were sent to the requesting laboratory, but in four instances the entire set was requested and sent. In one instance a selection of four cultures specified in connection with tests on coating materials and hookup wires was made available to the American Type Culture Collection to serve as a source of supply for industrial laboratories.

The cultures which were sent to specialists for final identification were primarily those of the genera *Aspergillus* and *Penicillium* and their allies, *Fusarium* and its relatives, or *Mucor* and related forms. The practice of referring species of these difficult genera to experts for identification was followed in order to expedite this phase of the work.

The bacterial cultures were transferred to the TDAC Bacteria Culture Collection (see Section 2.3) and the yeast cultures were sent to the University of California where studies on yeasts were being conducted for the Office of the Quartermaster General.

2.2.4 Isolation and Purification or Separation of Cultures

The cultures isolated in the course of field studies were supposedly pure, that is, they contained only one organism. However, for the most part they had been isolated only recently in field laboratories under difficult conditions and in most cases had been transferred only once from the original petri dish cultures on which bits of yarn or other suitable inoculum had been placed. As a result, a considerable portion of these, in some lots over 60 per cent, proved to be mixtures. Hence, considerable time and effort were required for separating these mixtures into the two or more individual cultures which were represented. Such problems as these are ordinarily encountered even under the most suitable conditions and it was realized that such culturing and reculturing of the field material would be an essential part of the work, and it was for this reason that the TFCC was regarded as a necessary corollary to successful field studies.

Certain of the mixtures encountered gave particular difficulty in separation. One of these was a mixture of slowly growing, nonsporulating mycelium with a rapidly developing, abundantly sporulating contaminant such as *Fusarium*, *Mucor*, or *Trichoderma*. Mixtures of two nonsporulating mycelia of approximately similar growth rates and superficial appearance also appeared to be very troublesome. To separate such mixtures as these required repeated attempts in which a wide variety of specialized isolation procedures were employed.

Contamination with various mites was also experienced to a considerable extent in some lots of the cultures received. Mite contamination is undesirable particularly in that it superimposes an added difficulty in obtaining pure cultures. To prevent the spread of mites and disastrous infestation of other cultures on hand, the use of mineral oil to cover the actively growing cultures proved highly successful.

As a result of this subculturing of the cultures which were received, the number of individual fungi in the collection was increased. Whereas the cultures received totaled 4,163, the others separated later in the purification of the mixed cultures would increase the actual number of different fungi to around 4,500.

2.2.5 Maintenance of Cultures

The fungi deposited in the TFCC were maintained both in the active growing state and also preserved for long-time survival in a dormant inactivated condition. It was necessary to maintain active growing cultures for purposes of distribution to other laboratories as well as for use in identification of the organisms. The program on long-time preservation of the cultures was undertaken in order to lessen the task of maintaining all cultures in a viable condition and to conserve for future study this highly important and significant collection of tropical fungi.

Maintenance of Cultures in the Active State

Potato-maltose agar of the following formulation was used to maintain active growing stock cultures: 300 g potato, 10 g maltose, 20 g agar, 1 l water. This proved to be most successful for a wide range of different fungi, both for securing abundant sporulation and for supporting long continuing normal growth. For comparing the colony growth, color production, and other characteristics essential for identification, the standard comparison media of different formulations were used as recommended by the experts in the various taxonomic groups represented. It was also necessary to use special culture media for growing those fungi which proved to be very slow in developing diagnostic characteristics, including nonsporulating mycelia. Special culture procedures were also employed in securing critical developmental stages for proper identification of many of the forms.

Maintenance of Inactivated Cultures—Lyophilization

Inactivation of fungi by this method involves the use of a small amount (.05 cc) of a dense suspension of spores in some lyophilic colloid such as horse serum or skim milk. This suspension is placed in small containers, such as Pyrex glass tubing (7 mm OD), and is instantly frozen at a low temperature (—50 to —60 C). After freezing the spore suspension is dried by pumping off the water vapor by sublimation under a vacuum of about 100 μ of mercury until a dry pellet is obtained. The glass tubing is then fused off and the container with the pellet is hermetically sealed.

This method had originally been used for the inactivation of bacterial cultures and had proved highly successful except in the case of certain notably sensitive and vulnerable forms. Recently the procedure has been successfully applied to the conservation of selected cultures of yeast. A small apparatus had been constructed by the Harvard Laboratory for preserving the collection of fungi previously present there. Meanwhile, extensive experiments had been conducted at the Northern Regional Research Laboratory in which this method was applied to the preservation of numerous fungus cultures, particularly species of Penicillium. A copy of a manuscript in the process of publication, which appeared in the July-August 1945 issue of *Mycologia*, describing the results of this experimentation was loaned to the culture collection, and this proved to be very useful and advantageous to the program.

The lyophil method of long-time preservation of fungi can be applied to a wide variety of forms but not to all. Technical difficulties as well as the failure of certain types of spores to withstand the relatively drastic method of treatment prevented this method from being used for all organisms represented in the collection. Nevertheless, in addition to the fact that the lyophilization program provided a means whereby these cultures could be preserved for intensive study at a later date, it saved considerable expense and energy by reducing the maintenance program and allowing, as a result, more time for the critical task of identifying the cultures at hand. By October 31, 1945, a total of 1,734 cultures was preserved by lyophilization, and the program was continuing at the rate of around 300 cultures per month, mostly in triplicate.

Maintenance of Inactivated Cultures—Inactivation under Mineral Oil

By this method, young vigorous colonies growing in ordinary 6-in. test tubes on agar medium are conserved by pouring in sterile mineral oil until the tip of the agar slant is submerged about 1 to 1½ cm below the surface of the oil. This layer of mineral oil cuts down evaporation and slows down the activities of the colony so markedly that, if kept in a refrigerator or even in a cool room temperature, the cultures, while they may show some growth, will retain their viability for as long as two, three, or even more years.

This method also had originally been used for the conservation of bacterial cultures. Reports had also been made on the successful application of this preservation method to fungi for periods of at least 18 months. The advantages and disadvantages of this method of conservation of fungi are discussed in OSRD Report 5681[2] and they are based on the broad experience gained during the activity of the collection. In general, it was felt that the advantages far outweighed the disadvantages in using this technique. Many factors in its favor are cited in addition to the one cited previously concerning the control of mites which may be present in the cultures.

As with the lyophilization program, this program involving the conservation of cultures by the use of mineral oil represents the first instance in which this method was applied to such a large number of cultures of such diversified types. In all [illegible] cultures were thus conserved by October 31, 1945. Therefore, the cultures which were conserved by both the use of mineral oil and lyophilization represented approximately two-thirds of those present in the collection.

2.2.6 Study and Identification

For the most part, the study of the fungi present in the collection was confined to that which was essential for their identification. A considerable amount of study was devoted to developing or modifying methods to facilitate, expedite, and improve the procedures necessary for the preparation of such large quantities of material for identification. For reference purposes, record was made of critical or important fungi by retaining them as dried herbarium specimens or by preparing Kodachrome photographs for accurate permanent records to show the color and growth characteristics of colonies grown in petri dish cultures on standard comparison media.

The most significant and essential activity in connection with the study and identification of the fungi was the preparation of permanent microscopic slides which served not only as a basis for identification but continued to serve as essential reference material for subsequent comparison and identification. This slide collection in itself constitutes a valuable and indispensable record of the fungi.

A total of 3,821 such slides was prepared by October 31, 1945. Their preparation, in many cases, involved various specialized techniques directed to secure and prepare the critical material necessary for identification. The various techniques employed and the use of a new material which was adopted for sealing cover glass mounts are described in a report issued by TDAC, OSRD 5681.[2]

The majority of the determinations and identifications were made by the expert personnel of Harvard University associated with the contract. Of the 1,032 cultures which were sent to specialists for identification, as indicated in Section 2.2.3, identifications of 368 were completed and returned by the end of October 1945. By this date a total of 2,275 identifications had been made. More than two-thirds of the identified cultures were isolated in the Panama Canal Zone. The appendix of OSRD Report 5681[2] lists in alphabetical order by genera and species these identifications.

2.2.7 Conclusions—Points of Interest

Instances of Association and Interaction between Fungi

Certain stubborn associations of organisms have been encountered repeatedly and these have required considerable skill and patience to separate into pure cultures. The frequency of occurrence, the compatibility, and stubbornness of these associations suggest that they may be advantageous rather than merely chance combinations among the mixed populations common under natural conditions. These associations, as indicated and discussed in OSRD Report 5681,[2] involve species of Trichoderma and Botryodiplodia, Trichoderma and Fusarium, Pullularia and Penicillium, Botryodiplodia and Mucor, Fusarium and Mucor, and Fusarium and Pestalotia. Another such association frequently encountered was the mixture of a small yellow rod-form bacterium with Pullularia or with the two Phycomycetes, Blakeslea and Choanephora. Two instances of parasitic association of fungi were encountered. One involved a Septonema-like imperfect fungus parasitic on and in the mycelial filament of the Phycomycete mold, Zygorhyncus. The Septonema was finally isolated from the Zygorhyncus through its rapid growth on such cellulose containing substrata as mineral salt solution plus filter paper, on which the Zygorhyncus developed only meagerly. The other involved a very delicate slender filamentous organism so inconspicuously parasitic in a Stachybotrys culture from Australia that it escaped notice for months but when discovered was traced through all successive transfers back to the original culture tube. By use of this same culture medium these two organisms were separated; interestingly enough, the parasitic organisms which had Actinomycete-like characteristics outgrew the reputedly cellulose-preferring Stachybotrys. It was noted that although the collection contained a number of cultures of *Penicillium rugulosum,* well known for its frequently and usually destructive parasitism on species of Aspergillus, especially *A. niger,* all of the cultures were isolated not as parasites on molds but as saprophytes on textiles and other exposed materials.

Among the instances of interaction between fungi which were noted in the course of the work was one of particular interest because it involved the stimulative action of substances produced by one mold on the sporulation of others which had previously produced spores in only meager amounts. This proved to be of practical value because adequate spore loads for lyophilization were thus secured. Cultures of Blakeslea are difficult to maintain because they sporulate only rarely and sparsely and those present in the collection were no exception. Chance contamination in petri dish cultures of Blakeslea were observed to stimulate spore production. In further experimentation, crude sterile filtrates from the growth of the contaminant

Penicillium on liquid media were added to various nutrient agars and produced abundant sporulation by this species of Blakeslea. Further investigation may reveal the nature and mechanism of this stimulation.

Problems Presented by Nonsporulating Mycelia

Because of the disproportionate amount of labor involved in obtaining sporulating cultures of these organisms, identification has not been made other than to assign them to major groups of fungi when possible. The lyophil technique cannot be applied to these and all of them have been conserved under mineral oil for study at a later date. Many of them apparently play an active part in deterioration, especially in the degradation of cellulose. They are common in nature and number 330 cultures or about 8 per cent of the total number in the collection. Separation of these organisms from contaminants and their maintenance in active culture present numerous problems and difficulties but these have been lessened considerably by using the mineral oil conservation technique.

Frequency of Representation

As OSRD Report 5681[2] points out, attempts to use the frequency of representation of fungi in collections as a basis for conclusions as to their signficance in deterioration must be made with due consideration of the factors involved. Ordinarily, it would be concluded that those forms represented most frequently would be those organisms most concerned in any deterioration process. However, there are many interacting factors which must be taken into consideration in evaluating the significance of such frequencies. Such factors as the geographic locality, the seasons, the nature of the article from which the organism has been isolated, the exposure given to the article, and the method and medium used in making the isolation are important and must be evaluated accordingly.

In the case of the original textile exposures in Panama adequate information on many of these interacting factors has been secured and some sound preliminary conclusions have already been presented in OSRD Report No. 4807[9] issued by TDAC. However, further detailed analysis remains in evaluating the significance of the occurrence of the various fungi, particularly comparison with exposure tests conducted later as indicated in Section 4.4.7. At the date of the last report, a total of 1,330 identifications of fungi isolated from the original textile exposure had been made; this represented practically the entire series of cultures.

The frequency of representation in this 1944 series is of interest. The genera most frequently represented are Penicillium with 195 cultures out of the total 1,330, Aspergillus with 56, Fusarium with 156, Trichoderma with 145, Pestalotia with 106, Pullularia with 100, and Botryodiplodia with 78, these seven comprising 836 cultures, or 63 per cent of the total. In contrast certain common and very widespread genera show notably meager representation, Phoma comprising only 18 cultures, Cladosporium 11, Alternaria 3, Rhizopus 7, and Syncephalastrum 1. Certain other genera, now well known in the deterioration program because of their destruction of cellulose, are sparsely represented, Curvularia comprising 9 cultures, Brachysporium 7, Metarrhizium 2, Memnoniella 1, while neither Stachybotrys nor Chaetomium appear at all! The troublesome, yet important, group of the nonsporulating mycelia is not of course truly comparable to a genus since it is a heterogeneous, inclusive, miscellaneous assemblage of greater scope, yet for purposes of comparative analysis it is notable that these comprise 185 isolations, about 15 per cent of the total in this series and almost double the 8 per cent representation in our whole collection. Certain species show notable frequency, *Trichoderma viride* being represented by 134 cultures, *Penicillium citrinum* by 101, *Pullularia pullulans* by 95, *Botryodiplodia theobromae* by 76, *Penicillium westlingi* by 23, *Aspergillus versicolor* by 22, and *Pestalotia virgatula* by 14, these seven species including 465 isolations or 37 per cent of the total 1,330.

In contrast a relatively large number of species, some of them common and widespread, are represented only once in this 1944 series. Among these are 9 species of Penicillium, several of which are of common occurrence, 7 species of Aspergillus, most of which are common and widespread, and 5 species of Fusarium, all of which are widely distributed components of the soil flora. *Mucor genevensis*, here represented once, is of very common and widespread occurrence in soil; *Memnoniella echinata* is common on plant remains throughout the tropics, as is *Pestalotia royenae*.

It is noteworthy that the classic test fungi which have been accepted as standard organisms for acceptance and performance testing are certainly not frequent in this series. *Chaetomium globosum* does not occur at all in this set although in the culture collection as a whole it is represented by three cultures in other Canal Zone sets and by six from the Florida five

months' storage exposure test. *Metarrhizium glutinosum* is represented only twice in this series and occurs twice in the Florida sets. *Memnoniella echinata* is represented but once in this set in contrast to twice in other Canal Zone collections and four times in the Australian Mycological Panel set. *Stachybotrys atra* is not represented in this series although occurring in six cultures in the remainder of the collection. *Aspergillus flavus* is represented once versus ten times in the remainder of the collection, *Aspergillus niger* three times versus 23 in the remainder, *Penicillium luteum* twice versus seven; *Trichoderma viride*, however, is extremely frequent. It should be noted, however, that some of the cultures comprised in this inclusive identification are not of the type suitable for testing since they do not break down cellulose.

Certain general conclusions are drawn in OSRD Report 5681 with reference to the natural sources of the organisms which seem to be most concerned with deterioration in the Canal Zone.

Such species as *Trichoderma viride*, *Botryodiplodia theobromae*, and *Pestalotia virgatula* are shown in supplementary collections from the Canal Zone to be common in the vicinity on decaying vegetation and to be carried to the exposed textiles by air currents and by splashing, dripping, or wind-borne rain. *Pullularia pullulans* and the frequently represented species of Penicillium, Aspergillus, and Fusarium are common in the soil and readily transported in dust or spattered particles. Once lodged on the textiles the several most frequently represented fungi became predominant and were consistently predominant in all successive periodic isolations throughout the ten months' duration of exposure. On the other hand the rarity of Cunninghamella, with one isolation, in contrast to the comparative frequency of its close relatives, Blakeslea with 21 isolations and Choanephora with 18 isolations, is puzzling. All three are common in the vicinity and none of them use cellulose as a carbon source. Since Blakeslea and Choanephora occur naturally on flowers and succulent fruits while Cunninghamella commonly develops on such substrata as dung of herbivorous animals or on nuts rich in nitrogenous materials, it is possible that the relative absence of nitrogen sources in the textiles is responsible for the scarcity of Cunninghamella.

Comparison with Similar Collections from other Regions

Comparison of the organisms isolated from the original textile exposure test with a few available lists of fungi from other localities brings up certain points of interest.

Only 280 cultures have been identified from the Quartermaster Florida storage deterioration tests. The distribution of these in the principal taxonomic groups of fungi agrees rather closely with the taxonomic distribution of the fungi from the original textile exposure series. The genera Penicillium, Aspergillus, and Fusarium show the highest frequency of appearance in both the original textile exposure series and in the Florida storage deterioration tests. However, the genera Trichoderma, Pullularia, Pestalotia, and Botryodiplodia are represented far more frequently among the organisms from Panama than among those from Florida. However, Chaetomium and Stachybotrys are represented in the Florida collection more frequently than they are in the Panama collection. Cunninghamella is meagerly represented in both collections but the closely related genera, Choanephora and Blakeslea, which both occur in the Panama isolations are absent from the Florida collection even though they are both known to exist in that region.

A rough comparison of the Panama fungi with fungi isolated from deteriorated materials returned from Pacific areas can be obtained by contrasting the occurrence of the nine most frequent species in the Pacific list with the occurrence of the same species in the Panama list. From 1,000 isolations performed from 137 samples of deteriorated materials, a preliminary list of 658 identified organisms was kindly furnished by the Tropical Deterioration Research Laboratories at the Philadelphia Quartermaster Depot which performed this investigation.

The following list compares these nine most frequent species among the Pacific fungi with their frequency in the Panama isolations; representation of the genera Pestalotia, Chaetomium, and Fusarium is also included.

	Pacific Series	Panama Series
Aspergillus niger	45	3
Memnoniella echinata	35	1
Aspergillus flavus	30	1
Aspergillus sydowi	24	2
Penicillium bourgerianum	17	0
Aspergillus terreus	16	0
Trichoderma viride	16	134
Botryodiplodia theobromae	12	76
Pullularia pullulans	10	96
Pestalotia	4	106
Chaetomium	39	0
Fusarium	43	156

OSRD Report 5681[2] compares the cultures from Panama with those reported as being important in

tentage and cordage deterioration in India.[5] In this report 74 species are listed. In general the fungi of this list closely parallel those from the Panama textile exposure, but there are certain striking discrepancies between the two lists. The organisms most frequently isolated in India during different seasons are either absent or only meagerly represented in the Panama collection. The only exception is in the case of species of Fusarium which were isolated abundantly from both regions. The differences may possibly be accounted for by the fact that different culture methods were used in the isolation of the organisms.

It will remain for future detailed analyses involving precise comparative studies to evaluate the significance of agreement or disagreement in the frequencies of organisms isolated from different regions, such as have been discussed above.

GENERAL SIGNIFICANCE OF THE FUNGI

Examination of the list of fungi from the Panama textile exposure test, with the assumption that they constitute a representative cross section of the mycological flora concerned in the deterioration of cotton fabrics in the Canal Zone, does not reveal a specialized individual flora distinctive or restrictive with respect to locality, sources, substrata, or activity. The primary source of the organisms is from the complicated flora of the soil while a secondary source is from the more restricted flora of decaying plant remains. Practically all the organisms are included in published works. Many of the fungi are not restricted to the Canal Zone and are widely distributed in subtropical and temperate regions. The organisms are a conglomerate, heterogeneous assemblage including forms which are well known in connection with the spoilage of food and pharmaceutical products, plant diseases, human diseases, such as ear and skin infections, and sources of antibiotic substances of potential therapeutic value. This is only a brief survey but it does indicate that those fungi which have been assembled in tropical deterioration studies have broad significance and represent interesting scientific possibilities and exploitable practical potentialities.

NEW GENERA AND NEW SPECIES

In addition to the known fungi which comprise the bulk of the organisms present in this collection, there have been encountered representatives of eight different genera and fifteen different species which were previously unknown. Practically all of these were isolated in the course of the original textile exposure and when judged on the basis of the unusual frequency of new forms in collections, this constitutes an inordinately high percentage of new organisms. OSRD Report 5681 indicates the importance of the new forms to tropical deterioration and to the science of mycology.

2.3 BACTERIA CULTURE COLLECTION

The bacteria cultures which served as the nucleus of the Bacteria Culture Collection [BCC] were those isolated in field studies on the deterioration of textiles by the Panama Science Mission. The results of these field studies are given in OSRD Report 4806[a] issued by TDAC and these are briefly summarized in Section 4.5.

It was not possible to identify fully the isolated bacteria in the field laboratories and all cultures were returned to this country pending decision to determine the identity of the organisms. Two general classes of bacteria were isolated from deteriorated tents and tarpaulins in use and experimental test fabrics, these being bacteria capable of destroying cellulose and noncellulose-destroying bacteria. The importance of the cellulose-decomposing forms is obvious, and the noncellulose-decomposing forms were present on the fabrics in such large numbers that it seemed probable that they played an important part in the biological deterioration of the fabrics.

The significance of these preliminary results was recognized and it was recommended by TDAC that the BCC be established for the purpose of identifying and preserving these cultures for future study. Accordingly, the collection was established at the Alabama Agricultural Experiment Station of the Alabama Polytechnic Institute with the cooperation of the Soil Conservation Service, U. S. Department of Agriculture.

The identifications which had been made by October 31, 1945 are summarized in the following section, based upon OSRD Report 5682.[7]

2.3.1 Identification of Isolated Bacteria

As with the TFCC, the enormous task of identifying the large numbers of bacteria which were deposited in the BCC could not be completed by TDAC. Bacteria isolations from the Panama field studies con-

sisted of 400 odd cultures and their sources are indicated in Appendices 3 and 4 of OSRD 1806.[*] In addition to these there were approximately 700 cultures deposited in the collection by Quartermaster laboratories: these were isolated from deteriorated materials returned from combat zones, mostly Pacific regions. Because of the interest and importance of knowing the identity of these bacteria to the program of the Office of the Quartermaster General, the contract under which the studies were conducted was continued by that office and the identification of the isolated bacteria has been included among the research projects which have been given top priority in the Quartermaster program.[*]

Identification of Cellulose-Decomposing Bacteria

Eighteen of the 37 cellulose-decomposing bacteria isolated by the Philadelphia Quartermaster Laboratory appear to belong to the Cytophaga group of bacteria. It has been definitely determined that ten of these produce microcysts and except for one culture they all have been identified as *Sporocytophaga myxococcoides*. Further studies are necessary to determine whether the rest of these members of the Cytophaga group form microcysts as well as the identity of these cellulose-decomposing forms which do not belong to this group.

All the 18 cultures of cellulose-decomposing bacteria from Panama have also been identified as belonging to the Cytophaga group. Most of these also appear to be *Sporocytophaga myxococcoides*. Almost half of these cultures were isolated from fabric either in contact with the soil or buried in the soil, but the remainder were isolated from tentage and tarpaulins in use. It is perhaps significant that these cellulose-destroying forms occurred on those fabrics in use which were found to be most seriously deteriorated.

The cellulose-decomposing bacteria in the collection which do not belong to the Cytophaga group have been less studied. They occur more widely than do the Cytophagas and appear to resemble Cellulomonas bacteria.

Identification of Noncellulose-Decomposing Bacteria

Of the 260 cultures of noncellulose-decomposing bacteria from Panama about one-half have been found to be either yeasts or fungi. Many of these were found to be contaminated with a small rod-shaped bacterium, which was impossible to eliminate despite varied attempts to do so. This association was apparently very intimate because in none of the various cultures attempted did the bacterium form separate colonies. Of the 200 Panama cultures which are bacteria, about 1/10 of them are cocci, small spherical organisms. The remaining cultures are practically all small rod-shaped forms; although separate studies of spore formation in the rod forms have not yet been made, certain observations suggest that spore formers are less prevalent than would be expected from a consideration of the conditions under which the organisms existed. The coccus forms were isolated from binocular lenses and leather stitching in addition to deteriorated fabrics, where they appeared to be more prevalent in advance stages of deterioration.

No positive species identifications of the noncellulose bacteria cultures have been made. However the organism *Bacillus mycoides* can be readily detected because of the characteristic growth habit on agar slants. On the basis of this characteristic this organism makes up at least 8.5 per cent of the isolates made at the Philadelphia Quartermaster Laboratory and 3.6 per cent of those made at the Jeffersonville Quartermaster Depot, but it is not found in the Panama isolates. *B. mycoides* is widely distributed and its absence from the Panama cultures is probably not due to differences in geographic location. It would seem to be more probable that since *B. mycoides* is a spore-forming organism, it either persisted during shipment of samples from the Pacific regions while less resistant organisms may have perished, or spores of the organism may have been added to the samples in the process of handling and shipment. Other studies have shown that in soils *B. mycoides* occurs principally in the spore form and apparently is not active in microbiological changes which occur, and it may act similarly in the microbial complex found on deteriorating tentage.

It should be pointed out that the identification of bacteria is a more laborious and time-consuming task than is the identification of most fungi. Because of the small size of these organisms, morphological characteristics are seldom critical in their identification, and recognition is based instead on physiological capacities or characteristics. Because of these reasons and because of the fact that necessary personnel to expedite the task of identifying the bacteria were unavailable, this task has not made as rapid progress as has the identi-

fication of fungi. With this collection, an excellent beginning has been made toward obtaining a clearer understanding of the role which these organisms may play in the deterioration of fabrics under field conditions. Although the tentative evidence at hand indicates that they may play a significant, though minor role in fabric deterioration, the full story cannot be obtained until the organisms are identified, and their important physiological characteristics with reference to fabric deterioration determined. This research would include determining the ability or inability of the organism to attack the components commonly used in the finishing of fabrics, and even perhaps supplementing these studies with additional field studies particularly designed to approach critical aspects of the problem directly, rather than to make a general survey which is primarily concerned with determining the incidence of bacterial deterioration.

Chapter 3

PREVENTION OF DETERIORATION OF OPTICAL INSTRUMENTS

3.1 INTRODUCTION

Reports from the United Kingdom, Australia, and the United States have stated that the problem of deterioration of optical instruments in the tropics is not a new one. It is indicated further in OSRD Report 6055[1] issued by the Tropical Deterioration Administrative Committee [TDAC] that problems with optical instruments occurred during World War II largely because instruments designed and manufactured for use in temperate zones were used in tropical areas. An Australian report[2] suggests that these problems assumed major importance because facilities for storage of instruments were extremely primitive in the early stages of the New Guinea campaign and because New Guinea is climatically one of the worst possible places for fungal trouble. In many localities, and certainly in the jungle itself, conditions of extremely high humidity prevail throughout the whole year without the alleviation of a dry season such as occurs in some tropical areas. As a result, optical instrument workshops, which were inadequately equipped and styled for even normal repair work, were unable to cope with the flood of fungus-infected instruments which descended upon them. Many types of instruments lasted only from four to eight weeks before becoming infected. Not only were instruments in use becoming infected, but new instruments awaiting issue in depots were found to be deteriorating rapidly on the shelves because of fungal attack. It was frequently necessary to clean and overhaul binoculars which had been reconditioned only a few weeks before. New or reconditioned binoculars which were shipped from Australia were found to be infected before they were issued from New Guinea depots.

3.2 STATEMENT OF PROBLEM

The various reports which are cited as references, as well as others to which no specific reference is made, indicate that under tropical conditions deterioration of one form or another occurs in the metal bodies of instruments, lenses, and prisms, as well as in lutings, greases, paints, gaskets, and other materials such as cork and rubber which may be used. Also, leather, metal, and canvas used for carrying cases may be seriously affected. In general, deterioration may be due to moisture alone or moisture in combination with fungus. No matter what the specific effect on any of the materials might have been, these effects did not prove to be serious, insofar as the function of instruments was concerned, until the glass surfaces themselves were obscured. This was a somewhat paradoxical situation in that fungi fouled glass most rapidly in service, although glass, along with metal, is itself least able to support fungus growth.

According to OSRD Report 4118,[3] fouled optical glass can interfere with the efficient operation of an instrument in two ways: (1) by interference and loss of light if the tarnished area is continually in focus, and (2) by causing permanent etching of the glass when such fouled areas are allowed to remain without cleaning. That report defines and discusses the main types of tarnish on glass surfaces which result from exposure to a hot humid climate. These are (1) physical and chemical changes in the glass surfaces resulting from prolonged exposure to humid air and condensed water, (2) the distillation of oily substances upon optical surfaces, and (3) the growth of fungi over the glass surfaces. The distillation of substances is also cited as an important factor in deterioration in a report from the United Kingdom.[4]

The corrosion of optical glass by moisture is considered in OSRD Report 6055.[1] This information is taken largely from a previously published report,[5] and its review is given below.

> *Water Attack.* In the presence of high concentrations of water vapor, the more soluble constituents of the glass migrate to the surface. If the amount of liquid water present on the surface is too little to dissolve the resulting hydroxides and carbonates, a slushy layer of crystals is formed. The loss in transparency may be slight in the case of a soda-lime-silicate window glass that forms scattered crystals of visible size, or the loss may be great in the case of a lead silicate glass where the crystals are microscopic in size and cover the surface completely. The rate of dimming depends on the composition of the glass. One month of exposure to humidity conditions of the type found in a tropical warehouse during the rainy season will cause barely visible dimming of the most durable glass compositions and will cause the most unstable glass compositions to become [illegible] instead of transparent.

The United Kingdom Report[4] gives the following consideration to [illegible] or dimming of optical glass by moisture.

The polished surface layer of glass has some properties differing markedly from those of the bulk of the glass. For example, the refractive index of the polished layer is, in general, quite considerably higher than that of the rest of the glass; further, the polished surface of the glass may be relatively unstable and, in particular, especially with crown glasses, free alkali may be present in the polished surface. In consequence, many polished surfaces have a natural affinity for water and if exposed to an atmosphere of relative humidity 50% and upwards will have a water inclusion in the surface. (In such circumstances the surface electrical conductivity becomes easily measurable.) The attracted water extracts more alkali from the glass and if the surface is subjected to conditions involving a cycle of varying humidity, successive solution and drying-out of alkali will take place and this may eventually result in the formation of a visible film. With many glasses this film is readily removable by wiping, but with others actual etching of the surface takes place. In barium and flint glasses, the metallic oxide content of the polished layer is higher than the normal for the glass and, as a result of exposure to atmospheric conditions, visible tarnishing may occur.

The Australian report[2] refers to the conclusions of one investigator with reference to the properties of glass surfaces and their relationship to staining and etching. These are as follows.

(a) All silicate glasses are very active and react in a fraction of a minute with water, giving on the surface of the glass a colloidal layer of silicic acid as a result of hydrolysis of silicates; the layer protects the glass from further decomposition by water.

(b) The thickness of this layer varies between 11 and 60 Angstrom units (1 A. U. = 10^{-8} cm).

(c) The colloidal layer is capable of absorbing other colloidal particles and electrolytes by 'exchange absorption.' That is to say, substances in the glass surface are replaced by others originally present in liquid in contact with the surface. Presumably this is the cause of the staining of glass caused when weak acids are left in contact with the surface.

Staining and etching of glass surfaces then may be possibly caused as follows:

(a) By the action of acids such as are known to be secreted by fungal cells (e. g. carbonic, citric, oxalic). Some plant cells have the power of absorbing ions from extremely dilute concentrations (energy necessary coming from the respiratory process), even to the extent of reducing the conductivity of the water around them to that of the purest 'conductivity water.' If fungi also have this power, continued solution of substances from the glass might occur, leading to real etching.

(b) By exchange absorption of ions between the living cell and the glass surface, similar to that which takes place between roots and clay particles.

It is evident, therefore, that the fouling or dimming of glass by moisture alone is neither unique nor to be unexpected, and that it is the property of the glass itself which makes it particularly susceptible to fouling by moisture alone.

2.2 PROBLEMS RELATED TO FUNGUS

The foregoing section indicates the deterioration of optical glass which results from moisture alone, but the quickest and the most striking type of deterioration of optical glass is that which results when fungi grow on or over the glass surfaces. When fungi are present in optical instruments, they are either obtaining nourishment from materials which are a part of the instrument or from foreign substances inside the instruments, such as dust or minute animals such as mites. It has been demonstrated[11] that under proper moisture conditions fungus spores which are present on clean glass surfaces are able to give rise to sufficient mycelium to be troublesome by using only the stored food which is present in the spores. Under conditions which favor more profuse growth of fungi, lenses or prisms may become opaque, wholly or in part, and markedly decrease the efficiency of the instrument.

The sources of infection of optical instruments by fungus spores have been indicated in the various reports on the subject. One such source is infection during assembly and repair. Fungus spores which gain entrance to the instrument during these operations remain there and give rise to mycelial growth when conditions for their germination become favorable. Another likely channel of infection is by means of growth of mycelium through holes or luting of the instruments. A mycelium which penetrates the instrument in this fashion may arise from spores which are in the luting materials or from spores present in instrument cases. It is possible for mycelia outside an instrument to penetrate the instrument through holes or cracks present in the luting or by digesting a path through the luting. Early observations on infected instruments indicated that minute animals, particularly mites, might play an important role in the infection of instruments. There has been no common agreement with reference to the significance of mites in the infection of optical instruments even though this topic has been widely discussed.[2,3,6,7,8]

It has been pointed out[2,9] that some of the fungi which have characteristically been found in optical instruments produce a certain type of opaque fruiting body (perithecium) which may have been mistakenly identified as mites, thereby overemphasizing the significance of mites in the infection of instruments. The majority of those who have studied the problem would concede that mites can and do furnish a likely source of infection, but on the basis of the reports which have been made, it seems that more evidence is necessary before mites can be regarded as a major factor in the infection of optical instruments by fungi.

Much attention has been given to the fungi which

have been isolated from infected instruments. The opinion was expressed early in the war that these fungi may consist of special forms or possess special properties which would peculiarly adapt them to the deterioration of optical instruments. However, as more information concerning these causative organisms was obtained, it was shown that the fungi involved in the deterioration of optical instruments did not represent special types nor did they possess any special properties. To be specific, fungi which have been isolated in Australian investigations are primarily species of Aspergillus and Penicillium. Of the fungi isolated from infected instruments returned from the Panama Canal Zone,[3] those which are judged to be most significant in the fouling of glass in the Canal Zone are Monilia and several species of Penicillium and Aspergillus. The fungi which have been identified during studies in British West Africa[9] as being most significant in the infection of optical instruments are *Monilia sitophila*, *Aspergillus niger*, and an unidentified species of Penicillium. From the above, it can be seen that the fungi which are primarily involved are merely "the weeds of the fungus world" and in no sense do they constitute any special group of organisms.

3.1 RELATIONSHIP OF MOISTURE PROBLEMS TO FUNGUS PROBLEMS

The conditions necessary for the development of fungi in optical instruments[1,3] have been briefly discussed. Over and above the general food requirements for fungi which have been mentioned above, the principal essential requirement is that of a rather high relative humidity. It has frequently been stated that relative humidities of approximately 70 per cent or higher are necessary in order for growth of fungi to occur. It is obvious, therefore, that if the moisture conditions within optical instruments can be controlled so that relative humidities of 70 per cent or higher would never be attained, most fungus problems would also be controlled. Initially and throughout most of World War II, however, investigations on the prevention of deterioration of optical instruments have been organized primarily around the control of fungus. At the outset, fungus problems were most easily detected and more spectacular and, furthermore, damage as the result of fungus action became more serious in a shorter period of time.

It is certainly conceivable that instances of moisture damage such as fogging or filming can occur without fungus fouling. These effects may be temporary. For example, exposed instruments, having been subjected to heavy condensation during periods of low temperature in humid tropical areas, would have abundant condensed water on internal optical surfaces, making the instrument completely unusable until that water had vaporized when the temperature within the instrument was raised. Moisture effects such as fogging or filming could also occur without fungus fouling. Table 7 of OSRD Report 4118[3] summarizes the incidence of fogging and fungus infection as well as other characteristics for experimental binoculars which were exposed for the most part in Panama. Comment on the fogging of fungicidally treated instruments will be made later. These data illustrate that although fogging and filming may occur without fungus infection, they are more generally accompanied by it. This was particularly true of untreated instruments which were used as controls.

3.4.1 Moisture Accumulation by Optical Instruments

Unless special precautions of sealing or dessication of optical instruments are taken, the design and construction of the instruments is of such a nature as to lead to an accumulation of moisture within the instrument in humid tropical areas where there is a marked temperature differential between days and nights. High temperatures during the day expand the air within instruments and force it out through small pores or apertures. When the temperature falls, moisture-laden air is drawn into the instrument. During subsequent "breathing" of the instrument as a result of marked fluctuations in temperature, moisture is not removed from within the instrument in the egress of air under high-temperature conditions. Such an accumulation of moisture provides fungus spores or filaments with sufficient moisture to satisfy their growth requirements. Different types of optical instruments have common features of design which give rise to such breathing. Although the emphasis in the program was placed on the deterioration of binoculars, it should not be interpreted that other types of optical instruments are not subject to moisture and fungus deterioration. Among those which have been reported in OSRD Report 4118 as showing fungus spotting during field observations in Panama are observation and director telescopes, range finders, height finders, and cameras.

Since optical instruments are susceptible to the

effects of moisture, once moisture makes ingress, an ideal environment is created for the rapid development and serious consequences of fungus growth. It may be reasoned that absolute control against the entrance of moisture would have been a more fundamental approach than control of fungus, but the fact cannot be disregarded that the controls against fungus which have been developed have greatly extended the service life of instruments.

3.5 CONTROL MEASURES

3.5.1 General Considerations

In the foregoing, the problem of deterioration of optical instruments has been stated as it has been visualized in the United States and Allied countries. Reference has been made to the more important reports from these sources to illustrate specific points of view and the emphasis and trends of the programs in the respective countries. It should be borne in mind that Australian, British, and United States work has been based upon field exposures in different tropical regions. There is no particular reason to believe that the field conditions in these regions are so marked in their differences that they significantly affect the evaluation of the contrasting methods of protection which have been developed. As will be pointed out, the most striking difference in results has been obtained from the exposure of instruments treated with Merthiosal in New Guinea and Panama. New Guinea exposures show that Merthiosal gives good protection against fungi whereas Panama exposures show that Merthiosal-treated instruments were less satisfactory than instruments treated with other fungicides. Such contrasting performances can perhaps be explained by differences in materials and their application, or by differences in test instruments rather than by exposure in different geographical regions. This seems to emphasize the desirability of a testing program in which comparable specimens would be exposed in different tropical areas. Such a program would certainly serve as an adequate basis for evaluating the different control measures which have been proposed. Furthermore, such a program would indicate the significance, if any, of local or regional climatic differences.

In the following sections further reference will be made to results of Allied investigations, but the principal emphasis will be given to the organization and results of the program as carried forward by TDAC and NDRC Section 16.1 which conducted the early investigations.

3.5.2 Sanitation Methods

Among the possible methods for controlling the deterioration of optical instruments are those which are indicated under the heading "Sanitation Methods" in OSRD Report 4118.[3] These are aimed at the elimination of all materials which would serve as sources of food for fungi and would include the elimination of infection during factory assembly and during reconditioning and repair. Therefore, if cork or paper pads are used in instruments they should be treated with a suitable fungicide. Likewise, the leather which is used in cases, straps, etc., should be given fungicidal protection. Among the effective fungicides recommended for this purpose are salicylanilide as indicated in Tentative Specification AXS-1416 Ordnance Department, U. S. Army, paranitrophenol recommended by many investigators, and terpineol which proved successful in West Africa field trials.[10]

It has been much debated as to whether or not leather is actually harmed or deteriorated by fungus growth. That particular question does not enter into these considerations. Leather binocular cases which are heavily fungus infested provide a ready means of contaminating the instruments themselves. Successful attempts have been made to eliminate this source of infection by the substitution of plastic cases for the standard leather carrying cases.[1]

In the cleaning and repairing of infected instruments, it is highly important to remove all traces of fungus growth not only from the prisms and lenses, but from the metal as well. For this purpose, ethyl alcohol and a stiff bristle brush can be used. The action of the alcohol is to kill all residual spores and all filaments are removed by the brush. If lenses need to be cleaned, lens paper dipped in alcohol will usually suffice. More refined methods for cleaning optical instruments, however, have been given.[11] If slight etching is present on optical surfaces, it may be removed by the use of rouge. The use of oil as a medium for rouge polishing should be avoided; if the oil gets on metal, it may redistill on the optical surface.

When optical instruments are serviced and repaired under field conditions it is only with great difficulty that the instrument can be kept free from fungus spores. This was recognized by the Australians and attempts were made to develop methods of treating or

sterilizing interiors of instruments after assembly.[3] These methods showed some initial promise, but they were eventually discarded. There is no question but that ideal conditions for assembly and repair of instruments in operational areas would be air-conditioned workshops and laboratories employing methods such as those used in factory assembly.

3.5.3 Dehumidification and Sealing

Dehumidification represents another approach to the deterioration-control problem in optical instruments. This is ideally accomplished by completely sealing the instrument in an atmosphere of sufficiently low relative humidity to exclude the moisture required to support the growth of fungi. In a well-sealed instrument the low relative humidity within the instrument should be maintained since moisture-laden air cannot have access to the interior of the instrument. This presents no problem in large instruments which are well enough sealed to hold gas under pressure. The use of silica gel as a dehydrating agent has been successful in many instruments, but details for its general usage are still to be worked out.

The major problem in maintaining a low relative humidity occurs with those instruments which are designed to be sealed with a putty-like compound. Such compounds as have been used vary widely in their properties and degree of effectiveness. Compound FXS-779 has been generally the most widely used and the best, but its performance has indicated that it is far from ideal. Satisfactory sealing of focusing eyepieces has been obtained with waterproof greases.

Considerable work has been directed toward development of new and more satisfactory sealing compounds. These investigations are described in OSRD Report 5684,[12] issued by TDAC. The requirements which a satisfactory sealing compound should fulfill are given in OSRD Report 6055,[7] as follows.

1. It should show excellent adhesion to metal surfaces and to glass. This adhesion should be retained after long aging.
2. The compound should demonstrate sufficient cohesiveness so that cracking or separation under pressure may be avoided.
3. The melting point should be below 300°F.
4. The compound should not flow of its own weight below 150°F.
5. At −60°F, it should not become brittle. However, any compound might be acceptable which became brittle at this temperature provided its properties of cohesion and adhesion were promptly restored when the temperature was raised.
6. It should be easily applied both in the assembly line, in the optical repair shop and in the field.
7. It should be possible to use the compound without the necessity of heating the surfaces to be sealed.
8. It should contain no constituents which might volatilize and redistill upon glass surfaces with the production of a scum over these surfaces.
9. It should not support fungus growth. If it does, this quality should be remedied by the application of a fungicide.
10. It should not be water soluble or water permeable.
11. Upon aging, the compound should not crumble or crack as a result of drying out.

In the laboratory investigations on sealing compounds, nine commercial preparations were tested and all of them were unsatisfactory on the basis of one or more tests to determine their all-around fitness for use in optical instruments. In addition, over 75 new formulations were subjected to a series of fundamental tests. Many of these were discarded but the most promising on the basis of these preliminary trials was submitted to optical laboratories for further evaluation. The most promising compound has the following formulation:

Darex thermoplast XTP-412 (Dewey & Almy Chemical Co.)	600 grams
Darex thermoplast STP-378 (Dewey & Almy Chemical Co.)	600 grams
Microcrystalline Wax No. 2310 (Socony Vacuum Co.)	120 grams
Paranitrophenol	13 grams

On the basis of the overall performance of this compound as recorded in OSRD Report 5684,[12] issued by TDAC, it adequately meets the requirements necessary for efficient performance of a sealing material. The only aspects unfavorable to its use were those pertaining to its stickiness and stringiness, particularly in cleaning off excessive amounts after application and its removal during the disassembly of instruments in which it was used. However, as it is pointed out in the report, so far as is known, it is virtually impossible to attain the essential characteristics of adhesion and cohesion except by use of a compound which would be sticky and stringy under these same circumstances.

3.5.4 Improved Storage Conditions

Many observations of optical instruments in storage which have been reported[3] indicate that the fungus problem is of significance during storage and precautions must be taken against it. Generally, where humidity is high fungus is found, and conversely, where humidity is controlled by air conditioning, fungus presents little or no problem. It is therefore obvious that air-conditioned storage space is highly desirable. This may well be practical at large bases or in warehouses where the necessary facilities exist but at outposts an entirely different situation is presented. For

safe storage of small quantities of instruments at such outposts, a portable dry chest in which a low relative humidity is maintained by means of a lighted electric lamp has been described.[13] Likewise, nonportable dry chests can be readily constructed.[1]

Problems connected with the long-time storage of optical instruments could probably be eliminated with the use of air-conditioned facilities. It is conceivable, however, that individual metal containers which were dehydrated or filled with an inert gas such as nitrogen would be better from certain considerations. It is understood that considerable investigation and application of this general method of long-time storage has been undertaken by the Army and Navy. Another approach to these problems which merits further consideration is the use of strippable films, either of the hot-dip or sprayable sort. Initial results of a promising nature were obtained by experimental applications of a hot-dip compound, but after 18 months' exposure to drastic jungle conditions, it was indicated that the compound tried was not thoroughly satisfactory. This general method, particularly the use of such films which can be applied by spraying, has been widely used on all other kinds of equipment and its applicability should be investigated further with reference to both large and small models of optical instruments.

3.5.5 Chemical Control

Of the various approaches to the problem of fungus control in optical instruments, control by chemical means has been given most attention. Various chemical methods of control have been recommended and if these alone were used there would no doubt be a material increase in the service life of the instruments to which they were applied. However, it was never assumed that these chemical methods would by themselves solve the problem. The best results from effective methods of chemical treatments can be obtained only when they are used in conjunction with methods directed to prevent deterioration by moisture alone. Furthermore, good sealing of instruments would prolong the effective period of a chemical treatment. Methods of chemical control have been directed to the control of mites as well as the control of fungus, on the basis that control of mites would render infection less likely.

Requirements of Control Chemicals

The requirements which should be met by chemicals used for the control of mites and fungi in optical instruments have been given as follows.[8]

1. It should prevent all fungus development in an instrument.
2. It should keep an instrument free of mites.
3. It should be sufficiently lasting to protect an instrument for many months.
4. It should not accelerate the normal moisture corrosion of metals used in optical instruments.
5. It should not increase the fogging normally resulting from moisture in most optical instruments in humid tropics.
6. It should not harm the finishes commonly employed on the surfaces of optical instruments.
7. It should not harm the cements used for sealing compound lenses.
8. It should present no health hazard to those employing the fungicide.

Treatment of Glass Surface

Experimental treatment of glass surfaces with inorganic salts or nonvolatile fungicides has not proven entirely successful. The attempt to use fluorides which are known to be enzyme poisons did not prevent the growth and development of fungi in Australian experiments.[2] Camera lenses with a hard fluoride coating have been reported to show heavy fungus growth and even etching through the hard surface. The germination of fungus spores can apparently be controlled by certain treatments, except when nutrition is gained from such sources as mites which crawl upon the glass surface and die. Another approach which has been made in this aspect of chemical control has involved the incorporation of fungicidal materials in antifogging substances which reduce surface tensions. Sufficient promise to warrant further investigation of this aspect of control has been obtained by incorporating Roccal (high molecular alkyldimethyl-benzyl ammonium chlorides) to the extent of 50 per cent in an antifogging compound applied to lens surfaces. These treated instruments have remained perfectly clean after exposure for over a year in Panama while all untreated controls have become badly infected.[12]

Merthiosal Treatment

Previous reference has been made to the use of Merthiosal (sodium ethylmercuri thiosalicylate) in Australia for chemical control of deterioration of optical instruments.[a] Recommendations for its use were made after extensive investigations showed that it served to control fungus growth. The investigations included both laboratory experiments and New Guinea field exposure tests. The compound is applied to instruments in a lacquer with which the interior metal

[a] This compound is referred to in recent Australian reports as MTS (anti mould).

surfaces, cork, and other materials are painted, and is mixed with cements and luting materials. From experiments to determine the effect of Merthiosal on mites it was apparent that the compound did not function as a mite repellent, but evidence was obtained that the compound will kill mites and reduce their numbers inside instruments. It was also noticed that fungus spores present on the dead bodies of mites did not develop. The general results of tests to determine the corrosive tendencies of Merthiosal when used with waxes, greases, or lacquers indicated that Merthiosal did not affect the protective power of paint in a 2 per cent concentration, nor did it accelerate metallic corrosion.

Contrasting results were obtained with Merthiosal- and Cresatin-treated instruments with reference to the prevention of fungus growth, the acceleration of corrosion, and the ability to repel mites. The difference between the performance of Merthiosal in Panama and Australia may well be due to slight differences in application of the materials used, as has been suggested. The nature and construction of the test instruments may also be an important factor, particularly in regard to the quality of the seal which can be made.[3] Further comparisons are necessary in order to determine the reasons for the discrepancy.

Two of the materials synthesized in Australian laboratories and closely related to Merthiosal have given more satisfactory results in Panama tests. These materials are n-butyl (ethylmercuri) thiosalicylate and methyl (ethylmercuri) thiosalicylate. They have both protected binoculars against fungus infection for a period of eight months, but the methyl derivative has induced considerable corrosion of aluminum.

Cresatin Treatments

In contrast to the use of Merthiosal by Australia in chemical control of fungus, Cresatin (metacresyl acetate) has been widely used in the United States. The early field experiments[6] which led to recommendations for its use have been described. Specific recommendations for its use have been made[14] and a more complete report[3,12] of the experimental program, particularly the results of long-time exposure tests, has been given. In early laboratory tests Cresatin showed promise over many other compounds, and as a result the field program in Panama was set up. The results of these exposure tests have served to strengthen and confirm the early laboratory results. Various methods of applying Cresatin in optical instruments[3] have been reported. The most promising method consists of incorporating Cresatin into ethyl cellulose to make a solid taffy-like block. The initial concentration of fungicide used in the mixture was 25 per cent. In an instrument, the block was fastened to the inner surface of the metal covering plate with an adhesive. As a result of further investigations similar Cresatin-ethyl cellulose mixtures, containing 50 per cent of the fungicide, were applied in aluminum capsules which were affixed to covering plates with cement after the capsule ends were crimped. The higher concentration gives a greater reservoir of the fungicide and enables a treatment to last for a longer period. By crimping the ends of the capsules only small pores which permit a gradual escape of the fungicide remain. Details of the use of these capsules in various types of optical instruments are given in OSRD Report 3803.[14] A 1945 report[12] indicates that Cresatin has kept binoculars free of fungus and mites in Panama exposures for 21 months. The early exploratory laboratory tests showed that Cresatin both kills and repels mites.

A quantity of 500,000 fungicidal Cresatin capsules were procured by Frankford Arsenal and distributed throughout the Pacific area for application to instruments during servicing and repair.

Considerable attention was directed toward the possible corrosive action of Cresatin. Upon hydrolysis of the compound, acetic acid is formed which will increase the normal moisture corrosion of brass, steel, zinc, and aluminum. This possibility has been freely discussed and openly considered in reports which have been made on the use of Cresatin in optical instruments.[3,5,14] Most of the objections to the use of Cresatin on these grounds were raised before the aluminum-capsule method of application was developed. With the inclusion of the Cresatin-ethyl cellulose compound in the aluminum capsules the possibility of corrosion of metals by the fungicide was greatly reduced. Field observations confirmed laboratory tests which showed that normal moisture corrosion of treated instruments is no more severe than if instruments are untreated and in many cases less severe. Investigations at Frankford Arsenal[15] showed that Cresatin in a 1/10,000 concentration at 104 F and saturated humidity does not harm metals and finishes used in optical instruments. In many instances where corrosion has been observed in field exposure of Cresatin-treated instruments, there were indications that this corrosion resulted because Cresatin was applied in excessive quantities and in such a manner that electro-

lytic action on metals resulted. Among the instances where corrosion of experimentally treated instruments was observed in field exposure this corrosion was no greater than that present in untreated instruments and, furthermore, the treated instruments remained usable long after most of the untreated controls had become badly fungus fouled. United Kingdom recommendations[4] stated that a 25 per cent concentration of Cresatin in ethyl cellulose gives no serious corrosion in optical instruments. This concentration is not as high as that recommended in the later work of TDAC, but the higher concentration (50 per cent Cresatin) has proven to be thoroughly satisfactory in short-time experiments. Only long-time tests which adequately evaluate fungus protection against possible corrosion will determine the limits within which Cresatin can be used to control the fungus fouling of optical instruments.

Other possible objections to the use of Cresatin have been indicated. Excessive concentrations of the fungicide may prove deleterious as a result of the solvent action on lens cements, since those commonly used are soluble in Cresatin. Only one instance of this difficulty was encountered in the numerous trial treatments at the University of Pennsylvania and in Panama, but an excessive concentration of Cresatin vapor was used. Laboratory exposures at Frankford Arsenal[15] and in England[16] have indicated that lens and prism cements are affected by Cresatin. A possible method of eliminating such effects is by the application of films of polyvinylidene chloride to the edges of lenses.

Thanite Treatments

There was developed as a result of other investigations a method of treating optical instruments based on the use of a contact fungicide and mite repellent.[17] It was visualized that this would be useful primarily to field service repair men and for instruments already in tropical service to which a vapor phase fungicide such as Cresatin could not readily be applied. Many compounds were screened by the use of a test method employing mites,[18] and the most promising of these compounds were subjected to other tests which would determine the dimming or condensation on optical surfaces. As the result of these tests, Thanite (fenchyl thiocyanoacetate) was given further trial when applied to instruments and finally recommendations were made for its general use. The recommended application is in a water soluble grease of the following formulation for screw threads, screw heads, and sealing end plates.

Carbowax 4500	65 parts
Carbowax 1500	35 parts
Sodium chromate	1 part
Fenchyl thiocyanoacetate	2 parts

In addition the following mixture is recommended for coating all interior surfaces of optical instruments.

Methyl alcohol	70 parts
Shellac	30 parts
Fenchyl thiocyanoacetate	2 parts

For nonreflective glass surfaces, a formulation as follows is suggested. This mixture should be incorporated in the proportion of one part mixture to one part total lacquer solids.

Asbestine	80 parts
Boneblack	5 parts
Santocell	15 parts

This experimental treatment has been applied to far fewer test instruments than has the Cresatin treatment, and exposure testing has for the most part been restricted to the specialized test employing extensive mite populations. There has been no indication that these tests have extended for a period any longer than four weeks. Only one instance is known of field-test results of optical instruments treated with fenchyl thiocyanoacetate. Among the instruments tested by a Frankford Arsenal mission to Panama in 1945 were two M17 elbow telescopes treated with Thanite. The details of the treatment were not available. These telescopes were exposed for a 3½-month period; one telescope showed marked fungus growth on the reticle and slight growth on the prism and the other showed a slight amount of fungus growth on the reticle. A control instrument showed considerable mold on most of the optical surfaces. Considering the limited application which has been given this fungicide with regard to both the quantity of instruments and the extent of actual field testing, there is no reliable basis upon which to base a comparison of such a treatment employing this contact fungicide with treatments employing Cresatin, a vapor phase fungicide. However, as indicated in Chapter 6, the Carbowax mixture containing fenchyl thiocyanoacetate has been widely applied to threads of photographic lens elements in the South Pacific area and has been successful in preventing the ingress of fungus and mites into these lens systems.

Only slight information is available on the corrosive action of fenchyl thiocyanoacetate. In the original experiment, it is reported that corrosion of treated

instruments is no greater than, and if anything less than, untreated instruments.[17] In a report from England[19] it was considered that the corrosive action of fenchyl thiocyanoacetate on copper, brass, and stainless steel was approximately the same as that of metacresyl acetate. Aluminum was not shown to be affected.

INHIBITORY RADIATIONS

A general statement[1] concerning this method of control of fungus infection has been given. In this method radium or radioactive salts are used. The alpha particles which emanate from such materials appear to be very effective in preventing any fungus growth. The incorporation of radioactive salts into a lacquer to be used in the vicinity of optical parts has been tried with considerable success. Perhaps a more effective method is the use of a radium foil which may be incorporated into the lens mountings in such a way that the stream of alpha particles comes into contact with the glass surfaces.

The Engineer Board has conducted extensive investigations at Fort Belvoir[20] on this method of applying radioactive materials to optical instruments. Results of only one field trial of this treatment are available. The Frankford Arsenal mission to Panama exposed one binocular treated in this fashion and one of the chambers became mold infected in the 3½-month exposure period. This method of treatment does not repel mites, and it is therefore possible that dead mites may appear on otherwise clean glass surfaces. Furthermore, adequate sealing is necessary in order to prevent dimming of glass by water vapor.

3.6 RECOMMENDATIONS FOR NEW DESIGN

The various controls of the deterioration of optical instruments which have been presented in the foregoing section have been developed primarily as a means of protecting old-model instruments. Various reports have pointed out the importance of design in combating the problems. Design is not only important with reference to the deterioration of new instruments, but also in permitting service and repairs. Associated with the improvements which can be achieved by new design is the choice of materials which in themselves are resistant to deterioration. The possibility that plastic fixed focus binoculars would prove highly efficient in tropical service was recognized from the start. Many comments have been made on the suitability of late-model Army binoculars for performance in the tropics. These newer instruments, although not immune to tropical deterioration, have proven to be much more satisfactory than the old-style instruments, many of which were in use. The investigations which have been made have had as their primary objective the protection and improvement of the service life of these old-style instruments which were used out of necessity. The many approaches to the problem and the different treatments in themselves will not entirely eradicate deterioration; in practice, each different form of approach or method is supplementary to others, i.e., satisfactory chemical controls are most efficient only with proper sealing.

Of the various methods recommended, all have not been given equivalent field trial. There is no reason to assume that the most promising of these methods which have been developed to date are the best which can be obtained. Once promising results were obtained in the investigations undertaken, a search for new and better remedies was continued. This attitude should continue to be held. Furthermore, complete comparative evaluation of field performance of the various treatments should also be made. Attention has frequently been called to the importance of field evaluations and this cannot be overemphasized, for accurate interpretations of effective preventive treatments can only be drawn from field evaluations.

Chapter 4

TROPICAL DETERIORATION OF TEXTILES

4.1 INTRODUCTION

The fact that much emphasis and attention was given to the deterioration of military textile and cordage items by microorganisms during World War II should not create the impression that the deterioration of these materials has only recently been recognized. The deterioration of textiles by microorganisms is a problem of long standing but one to which little attention has been given in the United States until recently. England, on the other hand, because of her exports of textiles to the Far East, and her numerous island possessions, recognized the necessity of protecting her shipments at least during transit and storage and developed an interest in fungus-proofing at an early date.

Much research has been done on the microbiological degradation of textiles. Prior to 1920 most published accounts on mold or mildew damage of textiles and cordage were concerned primarily either with a report of damage done or with the identification of the types of organisms involved. Since about 1920 there has been a much larger volume of work in this field, and considerable emphasis has been given to the development of methods for the prevention of damage to textiles and cordage by microorganisms. It is not the intent to review this early work on the subject; a comprehensive bibliography[1] prepared during World War II includes significant references to past work in the field.

Before World War II, the interest of textile manufacturers, of chemical manufacturers, and of consumers in the fungus-proofing problem was confined largely to the protection of such fabric items as shower curtains, awnings, and tarpaulins or the cordage employed by the fishing industry. When it seemed likely that much of our participation in World War II would take place in the Southwest Pacific, where the problems of supply and maintenance would be of major concern, the Army and Navy recognized that large quantities of equipment, particularly sandbags and tentage, would be serviceable for only a relatively short time, unless protected by a fungus-proofing agent. Early in 1941, certain branches of the Army and Navy initiated extensive programs to develop such preventive materials and to test their efficiency in the different applications required. Industrial laboratories, stimulated by the needs of the Army and Navy, expanded their research programs to find and develop new fungicidal materials, and as a result, new fungus-proofing compounds have been discovered and the uses for those already known have been considerably extended. By 1944, when the Tropical Deterioration Administrative Committee [TDAC] was organized, much progress had been made toward a satisfactory solution of the textile deterioration problems presented by tropical warfare.

OSRD Report 4513[2] issued by TDAC points out all of the foregoing and reviews the pertinent information on the subject which was available at that time, including information from the United Kingdom and Australia.

4.2 CAUSES OF DETERIORATION

The most important causes[3] of the deterioration of textiles and cordage are:

1. Photochemical degradation occurring in sunlight, particularly of cellulosic materials. Evidence would seem to indicate that not only cellulose itself may be affected by sunlight but also that the chemical agents which are added may be catalyzed to bring about changes which in turn may contribute to the degradation of cellulose.

2. Direct reaction under certain conditions between fabric and other materials such as finishing compounds, components of soil, or other substances with which the fabric or cordage may come in contact.

3. Deterioration by microorganisms which utilize the fabric or components of the finish as a source of food. These organisms may be capable of destroying the fabric directly or only of decreasing the effectiveness of the protective materials so that other factors then may operate to bring about deterioration of the fabric itself.

The TDAC studies have been largely concerned with microorganisms; however, in the course of these studies, significant information on other causes of deterioration was revealed, and their importance has not been neglected.

4.3 NEED FOR FIELD STUDIES

From information returned from operational areas, the existence of problems associated with the deterioration of textiles was substantiated. Sound criteria did not exist for evaluating the extent to which protective measures were adequate; furthermore, the problems which were presented were so complex and variable in nature that the need of analytical studies in the field was apparent. Accordingly, plans were made whereby such studies were to be undertaken in the Southwest Pacific area, but unfortunately, after the personnel and equipment for these studies were assembled, it was not possible to proceed.

4.4 FIELD STUDIES IN PANAMA

As an alternative, arrangements were made to conduct these field studies in Panama and the investigations which were intended to be made in the Southwest Pacific area were undertaken at Barro Colorado Island under the direction of TDAC. The general climatic characteristics of Panama and Barro Colorado Island, as well as the detailed climatic conditions which pertained during the period of test, are given in OSRD Report 4807.[3] The factors of rainfall, relative humidity, and wind movement, and their effects upon the results of the test are reviewed. In summarizing the influence of climatic factors on the results of the tests which were conducted at Barro Colorado Island, it was concluded that climatic conditions were not severe in terms of certain other humid tropical climates. If the significance of rainfall as the most important single factor in determining the deteriorative influence of a tropical climate is considered, it may be seen that other humid tropical areas have more severe climates than the Canal Zone. The occurrence of a dry season in Panama restricts the application which can be made of the test results in terms of performance in equatorial regions which have a heavy rainfall throughout the year. However, the occurrence of a dry season proved to be valuable with reference to certain aspects of the performance of the test materials.

4.4.1 Materials Used

For these field investigations on textile materials, the Office of the Quartermaster General furnished an elaborate series of panels, chiefly heavy tent duck and light cotton sheeting, treated with thirteen different mildew-proofing compounds and including suitable untreated controls. The specific treatments which were given to the individual panels are given below with the code numbers used to identify the panels.

Heavy Duck (11.9 oz)

C-51 Control series bearing no fungicide. The fabric finish consists of the Jeffersonville Quartermaster Depot [JQD] No. 242 finish of the following general composition:

42 per cent chlorinated paraffin	26 per cent
70 per cent chlorinated paraffin	13 per cent
Amberol M-83 (phenolic resin)	6.66 per cent
Rubbery pitch (asphalt)	3.7 per cent
Antimony oxide	20 per cent
Calcium carbonate	12 per cent

This mixture is applied in a single bath treatment with all ingredients incorporated in the mixture. The duck is dipped in the liquid (hydrocarbon solvent) and scraped free of excess.

C-52 Standard tent duck treated with the above JQD No. 242 finish but containing copper naphthenate incorporated in the finish to the extent of 0.35 per cent by weight of metallic copper.

53 Standard tent duck treated with the above JQD No. 242 finish but containing, incorporated in the finish, 0.175 per cent by weight of copper as copper naphthenate and 0.175 per cent by weight of copper as copper hydroxynaphthenate.

Shelter-Tent Duck (7 oz)

C-54 Control series bearing no fungicide. The fabric is finished with a two-bath water repellent containing mineral wax and aluminum acetate.

55 Shelter-tent duck treated with tetrabrom orthocresol so as to give 2 per cent by weight of the compound on the finished fabric. Two-bath water repellent containing mineral wax and aluminum acetate.

56 Shelter-tent duck treated with phenyl mercuritriethanolamine lactate so as to give 0.45 per cent by weight of metallic mercury on the fabric. One-bath water repellent, Fabrisec AA, containing wax emulsion only.

57 Shelter-tent duck treated with dihydroxydichlorodiphenylmethane so as to give 2 per cent by weight of the fungicide on the fabric. Two-bath water repellent containing mineral wax and aluminum acetate.

58 Shelter-tent duck treated with copper ammonium fluoride so as to give 1 per cent by weight

of copper on the finished fabric. One-bath water repellent of Fabrisec AA containing wax emulsion only.

59 Shelter-tent duck treated with trimethyloctadecyl ammonium pentachlorophenate so as to give 2 per cent by weight of the compound on the fabric. Two-bath water repellent containing mineral wax and aluminum acetate.

60 Shelter-tent duck (9½-oz Oxford) of a somewhat higher tensile strength than samples 54 to 59. Treated with copper 8-hydroxyquinolinate so as to give 0.31 per cent by weight of copper on the finished fabric.

COTTON SHEETING (OF VARYING WEIGHTS)

C-1 Medium-weight sheeting with dye only. No water repellent or fungicide.

1T Same fabric with dihydroxydichlorodiphenylmethane applied in a two-bath treatment. Water repellent.

1 Same fabric with dihydroxydichlorodiphenylmethane applied in a one-bath treatment. Water repellent.

C-2 Medium-weight sheeting with dye only. No water repellent or fungicide.

2 Same fabric with tetrabrom orthocresol. Water repellent.

C-3 Medium-weight sheeting with dye only. No water repellent or fungicide.

3PW Same fabric with 1 per cent Permacide AM-10 (a phenyl mercury compound). Water repellent containing wax only.

3PP Same fabric with 1 per cent Permacide AM-10 plus 2 per cent Perma Par R. Water repellent.

C-4 Heavy-weight sheeting with dye only. No water repellent or fungicide.

4N6 Same fabric with copper naphthenate applied as emulsion. Water repellent.

4NH Same fabric with copper hydroxynaphthenate. Water repellent.

4C Same fabric with copper as copper naphthenate applied in hydrocarbon solvent. Water repellent.

C-5 Medium-weight sheeting with dye only. No water repellent or fungicide.

5 Same fabric with trimethyloctadecyl ammonium pentachlorophenate. Water repellent.

C-6 Medium-weight sheeting with dye only. No water repellent or fungicide.

6PC Same fabric with 3 per cent pyridyl mercuric chloride. Water repellent.

6PS Same fabric treated with 1 per cent pyridyl mercuric stearate. Water repellent.

C-7 Medium-weight sheeting with dye only. No water repellent or fungicide.

7M Same fabric treated with 25 per cent phenyl mercury phenolate. Water repellent.

7P Same fabric treated with copper as copper ammonium fluoride. Water repellent.

8 Nylon netting with urea formaldehyde finish.

9 Cotton netting, insect bar, with dihydroxydichlorodiphenylmethane. Water repellent.

C-10 Heavy sheeting with (mineral) dye only. No water repellent or fungicide.

10 Same fabric with mercury as phenyl mercuritriethanolamine lactate. Water repellent. (This set was oil soaked when received in Panama.)

10X Same fabric with mercury as phenyl mercury salt of 2-mercapto benzothiazole. Water repellent.

4.4.2 Plan of Exposure and Study of Mycological Factors

In these field tests identical duplicates of each sample were exposed to four contrasting conditions of the natural environment: (1) exposure to full tropical sunlight, (2) exposure to shade, (3) exposure to contact with ground on the forest floor, and (4) exposure to burial in the soil. For each variation in treatment and for each of the four conditions of exposure, eight samples were supplied, making serial observations and determinations possible at eight different periods during the entire exposure. In all, 1,120 half-yard samples were used for these field studies which were followed closely for a period of 16 weeks and gave a preliminary indication of the efficiency of fabric treatment under tropical exposure.

Beside obtaining a comparison of the efficacy of the various treatments given to the experimental textile panels a major objective was to determine as far as possible in the field the identity, the frequency, and the sequence of appearance of cellulose-destroying and other fungi on the variously treated textiles. To this end a total of approximately 1,200 cultures of fungi were isolated from the various Quartermaster Corps samples in addition to 750 cultures which were obtained from other textile items of military equipment in the field and from decaying cellulosic plant materials. After the isolation of these organisms, they were dispatched to laboratories in this country for further

purification, when necessary, and identification. This laboratory phase of the investigation has involved considerable time and effort and it was not possible to complete the identification studies on the organisms isolated. However, valuable information was obtained on general aspects of the organisms involved.

4.4.3 Observations

Number of Fungi on Panels

An effort was made to determine the relative abundance of fungi on a selected group of sun- and shade-exposure samples by estimating the total amount of mycelial growth which developed by the use of different culture methods. Although the methods used were far from refined in their quantitative aspects, there was a surprisingly close agreement between comparisons made independently at different times. The following observations in these studies were made on culture plates prepared from sun and shade panels after 75 days exposure:

1. The abundance of fungi on the variously treated sun-exposure samples follows the same general sequence when measured on three different media. The shade samples show more variation, probably because of greater fungus-spore load derived from adhering particles such as fragments of wood, leaves, and insect feces.

2. The control samples have a more abundant fungus flora than the treated samples in both sun and shade.

3. The lowest number of organisms occurred consistently on plates made from the fabric treated with copper 8-hydroxyquinoline, both after sun and shade exposure. Certain plates from this treatment were virtually sterile with only occasional colonies of Penicillium sp. and a coral pink yeast which appeared to be the dominant organism.

4. Copper naphthenate, pyridyl mercuric chloride, and copper ammonium fluoride hold the fungus flora down to a low level under both sun and shade conditions.

Differences in the relative abundance of fungi on material similarly treated but exposed to sun rather than shade are probably due to a variety of factors. Among these are breakdown and loss of fungicide by sun and rain, divergent pH reactions of the fabric, ability of certain organisms to withstand one set of conditions and not the other, and variations in the quantity of spores derived from fragments deposited on the fabric surface by wind or from nearby vegetation.

Dominant Organisms on the Textile Panels

By carefully selecting from agar culture plates fragments of the organisms which were present in the greatest abundance, it was possible to obtain with considerable accuracy the dominant fungi which were present on the test panels. Limitations of equipment and time did not permit studies of this sort on all of the samples but it was possible to study the organisms from certain selected panels in this manner. The following list of dominant organisms is taken from OSRD Report 1807,[3] and the organisms were obtained from cultures made after the selected panels were exposed for 80 days to sun and shade. Additional observations on the dominant fungi involved are given in OSRD Report 5681.[4]

	Sun Exposure		Shade Exposure
C-51	Fusarium	C-51	*Botryodiplodia theobromae*
	Botryodiplodia theobromae		Fusarium
52	Pullularia	52	*Botryodiplodia theobromae*
			Pullularia
			Torula
C-54	Pullularia	C-54	*Botryodiplodia theobromae*
	Torula		*Blakeslea trispora*
			Pestalotia
57	(No cultures prepared)	57	Pestalotia (This was the only organism which appeared on the medium.)
60	Yeast, pink sporogenous	60	Penicillium sp.
C-1	Pullularia	C-1	Cladosporium
	Curvularia		Pestalotia
	Diplodia		*Blakeslea trispora*
4-C	Pullularia	4-C	Pestalotia
	Penicillium		Pullularia
			Penicillium
4-NH	(No cultures prepared)	4-NH	Pestalotia
			Penicillium
5	(No cultures prepared)	5	Pestalotia
			Pullularia
6-PC	Pullularia	6-PC	Pullularia
			Torula (?)
7-P	Pullularia	7-P	Penicillium
			Fusarium (?)
			Pestalotia
7-M	(No cultures prepared)	7-M	Pullularia
8	Pullularia	8	*Blakeslea trispora*
	Nigrospora sphaerica		Pestalotia
			Botryodiplodia theobromae

Three outstanding facts are immediately evident from the above listing of dominant organisms: (1) the small number of species, (2) the predominance of the genera Pullularia and Pestalotia, and (3) the

general absence from the list of any of the commonly used "test" organisms for measuring fabric deterioration.

This list should in no sense be interpreted as an analysis of the fungal flora on the test samples. With longer incubation of the plates a wide variety of other fungi appeared, differing as to the number of species on different treatments. These organisms which appear later may actually be present in considerable force but are either less numerous than those which appear first or else react quite unfavorably to the medium. There is no question but that the medium exerts a highly selective action on the results of these experiments, and in order to establish beyond question the dominant organisms on the fabrics it would be well to employ three or four media.

The extraordinary abundance of Pullularia, a highly polymorphic member of the Dematiaceae, is significant. This organism apparently has a high tolerance to copper and mercury compounds and is moreover able to withstand extreme environmental conditions such as are imposed by direct exposure to tropical sun. There is some information available which shows that Pullularia is capable of attacking cellulose, but the need for further tests on this point is indicated. There is a strong possibility that the Pullularia population is inordinately high because this fungus grew on the oil-soaked samples and on the oil-soaked areas of other samples to the virtual exclusion of other fungi. Inoculation by rain and wind from these Pullularia-rich areas of the fabric may explain the predominance of this form.

The abundance of Pestalotia on the shade-exposure series is interesting in view of its absence from or scarcity on sun-exposed panels. This genus comprised nearly 10 per cent of the total number of organisms isolated from the Quartermaster Corps textiles at Barro Colorado Island. Certain species of Pestalotia are active cellulose destroyers, and the frequent occurrence of the organism on duck and cotton sheeting treated with copper naphthenate and dihydroxydichlorodiphenylmethane is significant. Shade-exposure panels of shelter-tent duck treated with dihydroxydichlorodiphenylmethane yielded nearly pure cultures of Pestalotia, a fact which would indicate significant tolerance of Pestalotia to this compound. The possible tolerance of Pestalotia to a compound which is otherwise highly fungicidal would be well worth testing as an example of preferential fungicidal action.

These dominant fungi represented only a small fraction of the total number of the 1,200 cultures which were isolated. The complete range of fungi present on the samples furnishes an interesting list from the standpoint of the practical problems involved as well as on a purely mycological basis. Certain hitherto unknown forms have been discovered. As of March 1, 1946, complete identifications had not been made, but those which have been made include the majority of the fungi isolated. A preliminary listing of identified forms is given in OSRD Report 1807[3] and a more complete presentation of the later identification is found in OSRD Report 5681.[4]

Generalizations Concerning the Fungus Flora

From the observations and the experience gained during the course of isolating the numerous fungi from the experimental textile panels, the following generalizations were made concerning the fungal flora of the samples.

1. The fungus flora which develops on identical samples of fungicidally treated cotton textiles (and Nylon) differs widely between sun-exposure and shade-exposure conditions.

2. There is a pronounced difference in the flora which develops on textile samples of the same fabric, with the same dye and water repellents, but bearing diverse fungicides. Hence the composition of the flora on treated textiles exposed to tropical conditions for even a brief period (ten to twelve weeks) varies not only with exposure conditions but also with the chemical composition of the fungicide. There are thus two variables imposed at the outset on any generalizations which may be drawn regarding the nature of the deteriorative organisms on finished textiles exposed to tropical conditions. A third, and as yet unpredictable, variable resides in the difference between the fungus floras of diverse areas in the tropics.

3. Certain species of fungi capable of attacking cellulose have been found on a wide variety of treatments. These include *Botryodiplodia theobromae*, Penicillium sp., certain Fusaria, Pestalotia, and other distinct forms which have not as yet been identified.

4. There is a tremendous variation both in the number of organisms and in the number of species which occur on diverse treatments under given conditions of exposure. The number and species of the total growth is greatest on untreated canvas (i.e., devoid of fungicide). Of the fungicides tested the compound copper 8-hydroxyquinoline appeared to have by far the most active fungicidal as well as bactericidal effect. As a preliminary indication of their potential effect on fab-

ric, a selected group of 88 species of fungi isolated from the textile panels were grown on canvas strips placed on mineral-nutrient agar. The luxuriance of growth was observed and from this the degree of cellulolytic activity was estimated. This procedure of determining in a preliminary way the cellulose-digesting capacity of a fungus by the amount of hyphal production on cotton cellulose is open to some controversy, but, in general, if an organism is capable of producing a vigorous mycelium on relatively pure cellulose it would seem that the cellulose is furnishing a substrate for metabolism and growth. Moreover, microscopic examination of fibers from certain of the cotton strips which supported vigorous hyphal growth showed that the cell walls of the cotton hairs were undergoing enzymatic attack. Of the 88 forms selected more or less at random from a group of 125 isolates, approximately 50 species grew with considerable vigor on the canvas strips placed on mineral agar. It seems clear from this preliminary experiment that an unusually large percentage of the fungi isolated from the textile panels are capable of degrading cellulose. In this connection it may be noted that of 450 isolates of fungi taken from textile materials sent from the South and Southwest Pacific and tested for cellulose deterioration at the Philadelphia Quartermaster Corps Tropical Deterioration Laboratory, over 50 per cent showed significant cellutolytic activity.

4.4.4 Performance of Treatments

From the data derived by following at intervals the tensile-strength measurements made on the experimental and control panels, and by analyses of the overall conditions of exposure, the relative efficacy of the various fabric treatments was determined. The manner in which the panels were prepared did not justify differentiating between the possible causes of the results, e.g., the tendering effect (loss of tensile strength) of sunlight which was observed may have been more by action of the water repellent than of the fungicide, but there is no way to differentiate between these causes if both the water repellent and the fungicide are present on the same fabric.

From these studies it was shown that the following treatments were satisfactorily resistant to sun-exposure conditions.

Copper naphthenate (with screening pigments)
Copper 8-hydroxyquinoline
Phenyl mercuritriethanolamine lactate
Pyridyl mercuric stearate
Permancide plus Para R (phenyl mercury compound)
Copper ammonium fluoride } Some tendering action
Pyridyl mercuric chloride } Some tendering action

There was no statistical basis upon which to evaluate the various treatments under shade-exposure conditions.

The following treatments were satisfactorily resistant to ground-contact exposure.

Copper naphthenate and hydroxynaphthenate
Tetrabrom orthocresol
Copper ammonium fluoride
Copper 8-hydroxyquinoline
Trimethyloctadecyl ammonium pentachlorophenate
Pyridyl mercuric stearate
Pyridyl mercuric chloride
Phenyl mercuritriethanolamine lactate } Unsatisfactory on light cotton sheeting but effective on shelter-tent duck.
Dihydroxydichlorodiphenylmethane } Unsatisfactory on light cotton sheeting but effective on shelter-tent duck.

The following treatments were satisfactorily resistant to soil-burial conditions.

Copper naphthenate and hydroxynaphthenate
Copper 8-hydroxyquinoline
Pyridyl mercuric chloride
Pyridyl mercuric stearate
Copper ammonium fluoride
Dihydroxydichlorodiphenylmethane
Tetrabrom orthocresol

With due allowances for the variable factors in both the application of the treatments and the exposure of the test panels, an analysis of the exposure results provides a basis for selecting the combinations in the above lists which showed the best overall protective action. It was concluded that the following combinations gave the most satisfactory performance in the test exposures.

Copper 8 hydroxyquinoline
Pyridyl mercuric stearate
Copper naphthenate (screening pigments essential)
Pyridyl mercuric chloride
Copper ammonium fluoride

4.4.5 Conclusions after 16 Weeks of Exposure

Certain salient conclusions derived from this field study of experimental textile panels are given as follows:

1. Climatic conditions during the period of test were not severe. Rainfall, particularly during the latter part of the rainy season, was not heavy. Excessive wind movement with attending evaporation adversely affected the exposure tests and tended to affect the effects of high humidity. These considerations explain in part the surprisingly slow rate of deterioration with ground contact and shade exposure.

2. Sun exposure brought about greater loss of tensile strength in the fungicidally treated than in the untreated textile panels. Loss of tensile strength with sun exposure was particularly high in the case of the halogenated phenolic fungicides and the copper compounds, particularly copper naphthenate. Samples treated with certain water repellents only showed considerable loss of tensile strength in the sun, indicating photochemical breakdown of cellulose by such water repellent components as aluminum acetate.

3. The shade-exposure samples showed no significant change in tensile strength after 16 weeks of exposure. Visible mold growth appeared first on the sun-exposed samples. Of these, mildew was visible on fabric treated with tetrabrom orthocresol and Permacide AM-10 before it was detectable on the untreated controls under similar exposure conditions. At the end of 15 weeks of exposure virtually no mildew was visible on any of the treated or untreated shade-exposure panels.

4. Soil-burial exposure induced rapid deterioration of the textile panels although the resistance afforded by various treatments differed widely. The performance of certain compounds differed very considerably depending on the weight of the fabric to which they were applied. The compounds which gave the best protection under the conditions of this test were: (1) pyridyl mercuric chloride, (2) copper 8-hydroxyquinoline, and (3) copper naphthenate (solvent application).

5. The ground contact exposures proved to be retarded soil-burial tests. The results were essentially the same qualitatively although quantitatively ground-contact conditions were less severe.

6. Nylon netting proved to be indifferent to soil-burial conditions, to ground contact, and to shade exposure. Marked loss of tensile strength occurred, however, with sun exposure during the latter part of the testing period.

7. On the sun- and shade-exposure samples, pH measurements showed a more or less consistent decline between the fourth and tenth weeks. In general, pH readings were considerably lower in the case of the sun-exposed fabrics than in the shade-exposed fabrics.

8. On agar plates inoculated with yarns taken from selected panels after ten weeks of exposure to sun and shade, the abundance of fungi was highest in the case of the control samples, and by far the lowest on material treated with copper 8-hydroxyquinoline. Yarns from panels treated with copper naphthenate, copper ammonium fluoride, and pyridyl mercuric chloride were also low in the number of organisms present. All the treatments were not studied by this method, so that a complete comparison is not available.

9. The species of fungi present in abundance on the various treatments differed strikingly with the exposure conditions and with the chemical composition of the fungicide. A few treatments, when plated on agar, showed almost pure cultures of certain fungi which were present in abundance.

10. The dominant organisms on a large number of the treatments were cultured. The dominant fungi on the same fabric differed somewhat between sun and shade exposure. The following species of fungi occurred in the greatest abundance on the treated textile panels: Pullularia sp., *Botryodiplodia theobromae*, Pestalotia sp., Penicillium sp., and Fusarium sp.

11. With the exception of the genus Penicillium, none of the test organisms were isolated from the fabrics after prolonged exposure.

12. By correlating tensile-strength changes under various exposure conditions with the fungicidal action indicated by culture techniques, the following fungicides appeared to be the most satisfactory under the conditions of the experiment: Copper 8-hydroxyquinoline, pyridyl mercuric stearate, copper naphthenate (screening pigment essential), pyridyl mercuric chloride, and copper ammonium fluoride.

13. Examination of the various physical and biological factors of the tropical environment and their complexity and virtual impossibility of simulation demonstrate the necessity for further field research and testing in order to validate and render more realistic laboratory testing procedure.

446 Results after 60 Weeks of Exposure

During the initial 16 weeks of exposure the performance of the experimental textile panels was followed closely in order that the major objectives of the experiment would be attained. After 16 weeks it was not possible to continue the intense study of the textiles. However, there remained two complete sets of the sun-exposure series and three complete sets of the shade-exposure series. It was arranged that these re-

maining samples would also be subjected to tensile-strength measurements. For the sun-exposure samples, breaking-strength measurements were made at the 24-week exposure for one set and for the shade-exposure samples, breaking-strength measurements were taken at 24 weeks and at 30 weeks. No significant changes were noted over the results at 16 weeks. It was not planned to obtain breaking-strength values for the remaining set of sun- and shade-exposure samples at any fixed time; instead, these were to be allowed to remain on exposure until trial "thumb" tests revealed weakness in the fabric, and whenever a fabric was able to be torn by the thumb test it was to be harvested and broken. A few of the sun-exposure samples were harvested at 28 weeks, 36 weeks, 40 weeks, 56 weeks, and 60 weeks. Most of the remaining shade-exposure samples were harvested at 46 weeks.

After 60 weeks of exposure, the samples which had been treated with the following materials still retained sufficient breaking strength (thumb test) to warrant their continued exposure.

SUN EXPOSURE

HEAVY TENT DUCK

C-51	Fire-, water-, weather-resistant finish—no fungicide
C-52	Copper naphthenate
C-53	Copper naphthenate and hydroxynaphthenate
C-54	Control—no fungicide—two-bath water repellent
C-56	Phenyl mercuritriethanolamine lactate

LIGHT COTTON SHEETING

6PC	Pyridyl mercuric chloride
10	Phenyl mercuritriethanolamine lactate

SHADE EXPOSURE

HEAVY TENT DUCK

C-52	Copper naphthenate
C-53	Copper naphthenate and hydroxynaphthenate
C-55	Tetrabrom orthocresol
C-57	Dihydroxydichlorodiphenylmethane
C-58	Copper ammonium fluoride
60	Copper 8-hydroxyquinoline

COTTON SHEETING

C-2	Control—no fungicide
C-3	Control—no fungicide
4N6	Copper naphthenate applied as emulsion
4NH	Copper naphthenate, copper hydroxynaphthenate
4C	Copper naphthenate applied in hydrocarbon solvent—water repellent.
C6	Control—no fungicide
7P	Copper ammonium fluoride
8	Nylon netting, urea formaldehyde finish
10	Phenyl mercuritriethanolamine lactate
10X	Phenyl mercury salt of 2-mercapto benzothiazole

By comparing these results with the conclusions derived from the exposure test after 16 weeks, it will be seen that the treatments which showed best performance in the entire period were among those which were judged satisfactory on the basis of the results of 16 weeks' exposure. The fact that more samples remained in the shade-exposure series indicates that jungle shade does not impose conditions as severe as those in sun exposure. This contrast is probably primarily due to the reduced effect of sunlight. Among the compounds which gave the best protection in the shade-exposure series are copper naphthenate and copper hydroxynaphthenate. This applies to the light cotton sheeting as well as the heavy tent duck. The light sheeting samples with copper naphthenate treatment were harvested from sun exposure at the 28-week period. In contrast, these samples still remained on shade exposure after 60 weeks. However, the copper-naphthenate-treated heavy tent duck still retained considerable breaking strength after 60 weeks' sun exposure. On the light cotton these treatments were applied without the screening pigments which were applied with them on the heavy tent duck. These results strengthen and confirm the indications, which were apparent after 16 weeks' exposure, that fabric deterioration under field conditions can result from the action of sunlight on the fungicide or some other ingredient of the finish, thereby bringing about chemical deterioration of the cellulose itself.

4.4.7 Additional Exposures

The Office of the Quartermaster General arranged to have a duplicate series of these experimental textile panels exposed in Florida as well as in New Guinea. It was not possible to follow the results of each of these exposures as closely as the exposures in Panama; consequently, the results cannot be analyzed as thoroughly. It can be said, however, that the general performance of the individual protective treatments in the

case of these two additional exposures, closely paralleled the performance in the Panama test. The data which are available on these two additional exposures are being evaluated and compared with the results of the exposures in Panama.

The Office of the Quartermaster General desired to extend the field testing program which was undertaken by TDAC after the completion of the original test in Panama. One phase of the Quartermaster program involved a repetition of the exposure of the original textile panels but under conditions which more closely approximated actual service conditions. The results are now being finally studied but from early indications the performance of the various preventive treatments again closely paralleled the results of the original exposures. An objective of the later Quartermaster exposures was to determine more precisely the role of the individual components of the finish applied to fabrics and to gain a more extensive knowledge of the biological deterioration of fabrics. For this purpose a more extensive set of experimental textile panels was prepared and the exposure conditions to which these samples were subjected were modified in the light of knowledge gained from the original exposures. The results of this phase of the program are also currently being studied and analyzed.

4.5 RELATIONSHIP OF BACTERIA TO DETERIORATION OF TEXTILES

Investigations to determine the significance of bacteria in the tropical deterioration of textiles were also conducted by the Panama Science Mission. These field studies were made over a period of about eight weeks in contrast to the longer duration of the studies on fungi which are discussed above.

The results of these studies on bacteria are given in OSRD Report 4806,[5] which is the basis for the summary given in the following sections. The bacteria which were isolated during the course of these investigations were the nucleus of the Bacteria Culture Collection [BCC] which was established to identify the organisms and to preserve them for future study.

Identifications of the bacteria which were made by BCC are reported in OSRD Report 5682[6] and are discussed in Section 2.3.

4.5.1 Frequency of Bacteria on Exposed Fabrics

A quantitative estimate of bacteria present on deteriorating samples was considered important in drawing conclusions regarding the importance of bacteria in the deterioration process. For many reasons it was necessary to restrict these quantitative studies to only a few samples of the treated textiles which are enumerated in Section 4.4.1. These samples on which the quantitative studies were made, as well as those other samples from which bacteria were isolated, are indicated in OSRD Report 4806.[5]

Cellulose-Decomposing Bacteria

Twelve samples of tents and tarpaulins in use in the Canal Zone were studied for the presence of cellulose-decomposing bacteria, and from the majority of these samples (nine definitely, two probably) such bacteria were isolated. In general, the abundance of these bacteria appeared to be directly correlated with the degree of deterioration of the samples.

Studies on the treated experimental panels revealed that after a short period of exposure to soil contact, bacteria were present in large numbers on fabrics to which no fungicide or water repellent was added. On the fabrics tested which had been given either or both of these treatments the bacterial numbers were at a low level. Tests on a few fabrics after four weeks' air exposure indicated that bacteria were present on all samples. Samples which had been given sun exposure contained in general less than 100 bacteria per gram of fabric while samples which had been given shade exposure showed as many as 1,000 bacteria per gram of fabric.

A total of 145 isolations of cellulose-decomposing bacteria were made from the various samples studied in Panama.

Bacteria Other Than Cellulose-Decomposing Forms

Large numbers of these bacteria were found to be present on all samples studied, whether they were from tents or tarpaulins in use or from the treated experimental fabrics. Table 2 of OSRD Report 4806[5] indicates the numbers of bacteria per gram of duck which were found on the different experimental textiles under different exposures with the use of three different culture media for isolation. Numbers range from a low of 130 thousand per gram of duck to a high of 61 million per gram of duck for samples exposed in air for periods of four to six weeks. With reference to these noncellulose-decomposing bacteria, fabrics which were protected by a fungicide or water repellent, or both, showed far fewer bacteria than fab-

rics which had been given no preventive treatments. In all, a total of 175 isolations of these noncellulose-decomposing bacteria were made.

4.5.2 Significance of Bacteria in Fabric Deterioration

The significance which cellulose-decomposing bacteria may hold in the deterioration of fabric is obvious, and in the Panama field studies these forms were present in large numbers on fabrics which showed marked deterioration as evaluated by decrease in breaking strength. Noncellulose-decomposing bacteria were present on samples after four or six weeks' air exposure in such large numbers that it seems they may play an important part in the initial stage of deterioration of treated fabrics. As a result of this it was suggested that these noncellulose-decomposing bacteria may cause destruction of the treating agents which are applied to fabrics, thus causing a reduction in fungicidal value and possibly increasing chemical deterioration of the fabric.

The program of the Tropical Deterioration Research Laboratory [TDRL] of the Philadelphia Quartermaster Depot which has been summarized in Section 4.9 included comprehensive studies of bacteria, particularly cellulose-decomposing forms. These studies concerned nutritional requirements and optimal conditions for growth of these organisms in order to gain information which would be applicable to test methods and which would shed some light on the significance of these forms in the deterioration of fabrics under natural conditions.[7] This work also included tests to determine the effectiveness of commercial applications of different fungicides on the few bacteria which were studied in detail.[3] The results indicated that concentrations of fungicides which were inhibitory to fungi were also inhibitory to bacteria. The variations between the resistance of the bacteria used and a fungus used as a check were no greater than those which ordinarily occur between two or more species of fungi in regard to their resistance to different fungicides. Some of the results of the Panama field studies confirm this fact, since bacteria were present in fewer numbers on fungicidally treated fabrics than upon those which had been given no fungicidal treatment. In spite of these results, it seems that because noncellulose-decomposing bacteria were found on both treated and untreated fabrics in such prodigious numbers, even after relatively short exposure periods, further investigation of the exact role of these organisms in the deterioration of fabrics is warranted. These noncellulose-decomposing forms include far greater numbers of bacteria and show a much wider range of characteristics and properties than do the cellulose-decomposing forms which would be significant probably only in the destruction of the fabric itself. If it could be shown that these noncellulose-decomposing forms can somehow render protective treatments ineffective against fungi, the need for protective measures against these noncellulose-decomposing bacteria would be established.

4.6 THE EFFECT OF COPPER NAPHTHENATE ON THE DETERIORATION OF COTTON FABRIC

Preliminary evidence indicated that copper naphthenate, the fungicide so widely used by the Army and Navy on such items as tentage and tarpaulins, may itself contribute to a reduction in the tensile strength of these fabrics when exposed to sunlight and weather. Upon the recommendation of the TDAC Subcommittee on Textiles and Cordage, cooperative investigations to determine whether or not commercial copper naphthenate accelerates the deterioration of cotton were arranged with the National Bureau of Standards [NBS]. These studies involved extensive laboratory tests and analyses, as well as outdoor exposures of experimental fabrics under the different climatic conditions of Washington, D.C., Dickerson, Maryland, New Orleans, Louisiana, and Yuma, Arizona. It was not to be expected that an immediate solution of the problem would be achieved, but a good start has been made, and NBS intends to complete the investigations.

From an analysis of the data obtained thus far,[9] the following conclusions were drawn:

1. The copper naphthenate on the duck accelerated its deterioration.

2. The gray duck was more stable than the copper-naphthenate-treated duck except where there is evidence (fluidity results) of mildew action (New Orleans tests).

3. Loss of copper from the copper-naphthenate-treated duck is attributable not only to leaching by rain but to other causes. (There was 22 per cent loss of copper at Yuma in the first 30 days of exposure even though no rain fell during that time.)

4. Local differences in conditions of exposure (Washington and Dickerson) may affect the results of outdoor weathering to as great or greater extent

than geographical differences in climate (Dickerson and Yanis).

An effort was made to prevent or reduce the accelerating action of the copper naphthenate with antioxidants (pyrogallol, hydroquinine, alphanaphthol) and with an inhibitor (phenyl salicylate) but no reduction in the rate of deterioration was obtained.

Some data were obtained on the weathering behavior of copper naphthenate on cloth of different weights with and without the addition of a wax waterproofing compound, but these still remain to be analyzed. There also remain to be completed the final tests and analyses of exposed fabrics which were treated with (1) laboratory-prepared copper naphthenate free from copper sulphate, naphthenic acids, etc., (2) naphthenic acids, and (3) laboratory-prepared copper naphthenate plus copper sulphate and 1 per cent pentachlorophenol. The objective in these exposure tests was to contrast the performance of commercial applications of copper naphthenate, having various impurities present, with the purer laboratory-prepared compounds. The laboratory accelerated weathering tests which were performed on this series of treated fabrics did not correlate with outdoor exposures.

4.7 EFFECTIVENESS OF COMBINATIONS OF FUNGICIDES

Upon the recommendation of the Subcommittee on Textiles and Cordage, cooperative tests with NBS were also undertaken to determine whether mixtures of fungicides are a satisfactory substitute for fungicides in limited supply, and to extend the usefulness of fungicides which are good rot resisters but which afford little protection against surface growing organisms. As with the investigations on copper naphthenate, these still remain to be completed, but it is the intention of NBS to continue them as a post-war project.

It is indicated in a brief summary which has been made of this work[8] that in these investigations nearly all the available fungicides and mixtures of some of them were rated with respect to fungicidal efficiency when applied to cotton cloth in a series of concentrations. The evaluation tests employed were pure-culture tests using the organisms *Chaetomium globosum* and *Aspergillus niger*. The treated fabrics were tested "as is" and after exposure to leaching and laboratory weathering.

Cloths containing over 0.5 per cent copper in the form of copper naphthenate and cloths containing over 1.0 per cent of pyridyl mercuric stearate were rated excellent in all the tests whether the fungicides were used singly or in mixtures with other fungicides.

Experimental cloths which contained the following fungicides in amounts above those noted were rated excellent when tested "as is" but were given a lower rating after one or more of the exposure treatments.

Copper phenyl naphthenate	0.1% Cu
Dihydroxydichlorodiphenylmethane	1.0%
Copper oleate 0.6% Cu and dihydroxydichlorodiphenylmethane	1.2%
Copper phenyl naphthenate 0.2% Cu and dihydroxydichlorodiphenylmethane	0.9%
Phenyl naphthenate 0.2% Cu and pyridyl mercuric stearate	0.2%
Zinc phenyl naphthenate	1.0% Zn
Hyamine 3258	1.0%
Copper phenyl oleate	0.2% Cu
and dihydroxydichlorodiphenylmethane	1.0%
Phenyl mercuric acetate	0.5%
Tetrabrom orthocresol	0.5%
Puratized MC	1.5%
Puratized FL	1.0%
Pentachlorophenol	1.0%

Cloths containing fungicides reported below were rated poor in all tests.

Copper phenyl oleate
Copper oleate
Copper tannate
Copper tallate
Creosote
Copper phenyl oleate and creosote
Copper hydroxynaphthenate
Copper acetate and creosote
Methylene disalicylic acid
Bis-phenol S
Phenyl salicylate
Copper stearate
Zinc phenyl oleate
Naphthenic acid

In the work which has been completed, mixtures of fungicides have not proved to be superior to equivalent amounts of the components when used alone.

4.8 THE EFFECT OF LIGHT ON FABRICS

The problem of the effect of light on fabrics occupied the attention of the Subcommittee on Textiles and Cordage to a considerable degree and all available information on the subject was summarized for this group. Certain aspects of the problem were directly related to these studies on copper naphthenate and combinations of fungicides which are cited above. The results of the Panama field exposures, which indicated

that in sunlight exposure fungicidally treated fabrics performed less satisfactorily than controls which were given no fungicidal treatment, emphasized the importance of studies on the action of light. The desirability of inaugurating separate studies on this subject was considered but because of the long range nature of these studies and the difficulty in selecting a suitably qualified institution for conducting them, as well as the late stage of World War II, it was decided not to attempt to organize these studies under a separate project, but to incorporate as many aspects of the problem as possible with those investigations which were being conducted at NBS.

Valuable fundamental information on the action of sunlight on cotton cellulose has resulted from investigations sponsored by the Office of the Quartermaster General.[10] The adverse effect of light on the tensile strength of cotton fabrics has been recognized, and these investigations confirm this fact as well as the fact that it is the ultra[illegible] portion of the spectrum, rather than the visible portion, which is responsible for the effect. The evidence indicates the occurrence of a photochemical reaction which is independent of oxygen concentration and humidity, but affected by temperature, and results in an alteration of the cellulose. The products of the photochemical reaction are capable of oxidation, giving rise to oxycellulose. This ultraviolet modified cellulose has been shown to be more resistant to attack by the test fungus, Metarrhizium, than untreated controls. This may be accounted for on the basis that the modified cellulose possesses a substrate which affects the fungal growth and is supported by studies which demonstrated that oxidized cellulose derivatives are fungus resistant. However, the increased resistance to fungus attack is not considered to outweigh the harmful effects of ultraviolet light.[10]

The results of this work are regarded as important supplementary information to other studies on the deterioration of cellulose by microorganisms, and furnish a basis for the reported field observations on the mildew-resistance of exposed tents. The results also have a distinct bearing on the problem of photochemical deterioration of treated fabrics as was observed in the Panama field tests.

4.9 THE QUARTERMASTER PROGRAM ON THE DETERIORATION OF TEXTILES

In addition to the practical approach centering around process development and evaluation techniques for mildew-resistant treatments of textiles, the Quartermaster Corps organized TDRL in July 1944 at the Philadelphia Quartermaster Depot to extend the fundamental knowledge of the microorganisms encountered in the processes by which damage of textiles is brought about. The exploratory and experimental program of this laboratory has been directed toward development of the scientific background which is essential before further advances in the prevention of textile deterioration can be made.

The program of TDRL has furnished significant fundamental information on many phases of cellulose deterioration on which little or no information previously existed. A recent report outlined the progress which has been made to date on aspects of the microbiological degradation of cotton fabrics, the mechanism of degradation of cellulose, and methods of prevention of microbiological degradation.[8]

The work on the causal biological agents has been related to that of TFCC and BCC, which are discussed in Chapter 2. Whereas the bulk of organisms in TFCC were derived from Panama studies, the majority of organisms isolated under the Quartermaster program were derived from deteriorated military equipment returned from Pacific areas. In addition to the isolation and identification of these organisms their cellulolytic activity was determined, particularly for the fungi. In this work the Quartermaster Laboratory and TFCC cooperated closely.

Studies on the mechanism of degradation of cellulose involved investigations for determining the optimum condition for the growth of microorganisms, particularly those to be used for test purposes. In addition, comprehensive studies were made on the nutritional and environmental requirements of cellulolytic bacteria and fungi, and the effect which the environment exerts on the resistance of fabrics to microbiological attack. (See Section 4.8 for the effect of light.) Investigations were also undertaken to determine the chain of reactions which occur in the degradation of cellulose; these involve determining the relationship between molecular structure and microbiological resistance, the effects of enzymes, and other studies pertaining to the utilization of cellulose by microorganisms.

Attention has been directed to certain restricted aspects of methods for the prevention of microbiological degradation of fabrics. Methods involving cell toxicants (fungicides) or specific enzyme inhibitors have been studied only with respect to certain fundamental considerations. The impregnation of fabrics with micro-

biological-resistant resins has given encouraging results and the potentialities of such treatments are recognized. Considerable initial success has been experienced in the attempt to impart mildew resistance to fabrics by affecting a chemical modification of the cellulose itself. Test fabrics given a wide variety of chemical treatments in which a chemical combination between the cellulose and treating agent was probable showed complete fungus resistance when evaluated by a standard procurement test. The possibilities which this approach offers are being explored further. On the basis of these early results, chemical modification of cellulose may prove to be the most feasible approach to attaining a superior degree of mildew resistance in fabrics.

It will be noted that these investigations which have occupied the attention of the Quartermaster Corps are closely allied to those aspects of the problem which have been recommended for future investigations in Chapter 10.

Chapter 5

THE PROBLEM OF FUNGAL GROWTH ON SYNTHETIC RESINS, PLASTICS, AND PLASTICIZERS[a]

By *Alfred E. Brown*[b]

5.1 INTRODUCTION

A search of the scientific literature through 1944 reveals many references relating to the deterioration of textiles, leather, paints, metals, and wood products by moisture and fungi, as well as treatments devised to protect these materials, but not one publication dealing directly with the tropical deterioration of plastics or their components.[c]

This paucity of information is by no means unexpected because, prior to World War II, plastics were not giving any serious trouble of this nature in the temperate zones where they were most used. However, since 1942 the Armed Forces of the U. S. as well as those of Britain, Canada, and Australia, have moved large quantities of equipment into tropical areas.

The deterioration of textiles by microorganisms under tropical conditions is easily demonstrated and has been definitely accepted. As yet no such agreement exists in regard to many types of plastic materials. Because of the recent origin of this problem, as well as the rather limited investigations that could be carried on in wartime, insufficient data have led to differences of opinions regarding rather fundamental questions. For example, in some cases conclusive evidence that microorganisms grow on the plastic itself, rather than on surface contaminants like dust and fingermarks, has not yet been obtained. This is due to the fact that no effective treatment for cleaning plastics without removing lubricants, etc., has been forthcoming, and as a result, most plastics are tested as received. Also, even though fungi do grow on nutrients supplied by some plastic materials, there is considerable doubt as to whether either the properties or the composition of the materials have actually been altered. An even more controversial question, especially with reference to the performance of plastics in electric equipment, is whether fungi and moisture actually cause a greater deleterious effect on electric properties of plastics than moisture alone under the same conditions.

The NDRC Tropical Deterioration Administrative Committee [TDAC] established in July 1944 a Subcommittee on Synthetic Resins, Plastics, and Plasticizers to consider the problems of tropical deterioration of these materials.

5.2 SUSCEPTIBILITY OF PURE RESINS TO FUNGAL ATTACK

The major component of almost all plastic materials is the polymer itself. For this reason a study of the fungal susceptibility of the resin without added plasticizer, lubricant, and any other component is important. Table 1 lists the results obtained for representative materials by different laboratories.

A glance at the results shows why synthetic resins in general have earned the reputation of being resistant to fungus. The term resistant is used only to denote that the material does not serve as a source of carbon for the growth of fungi. Aside from the slight susceptibility of cellulose nitrate, polyvinyl acetate, and melamine-formaldehyde polymers, synthetic resins are indeed resistant to fungal growth. However, although the resins themselves do not support such growth, it must be remembered that neither do they inhibit it.

In view of the marked resistance of pure resins to fungal attack, it can be assumed that when plastic materials support growth, the addition of other components is most likely responsible for it. Such a hy-

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[a] Abridged from OSRD Report [illegible] of same title. Details regarding the test methods used to determine fungal resistance and a recommended test procedure, given in the original report, are omitted here and discussed in Chapter 8. The subject as discussed here represents a general review of the problem and includes information presented in OSRD Report 5383.[7] This chapter has been approved for publication in *Modern Plastics* by the OSRD Committee on Publications, and the original text is used except for changes in format.

[b] Research Associate, TDAC Subcommittee on Synthetic Resins, Plastics, and Plasticizers.

[c] Two articles of a general nature have recentl-

pothesis augers well for the future, since, as test results indicate which ingredients other than resins are fungus-resistant, the addition of such components may give rise to fungus-resistant plastics.

TABLE 1. Fungal resistance of pure synthetic resins.*

Substance	Extent of growth†	Laboratory‡
Thermoplastic materials		
Cellulose acetate	B,A,A	1,2,5
Cellulose acetate butyrate	A,A	1,5
Cellulose acetate propionate	A	1
Cellulose nitrate	C	1
Ethyl cellulose	A,A	1,5
Polyethylene	A,A	1,2
Polymethylmethacrylate	A,A,A	1,2,5
Polystyrene	A,A,A	1,2,5
Polydichlorostyrene	A	5
Polyvinyl acetate	C,A	1,5
Polyvinyl butyral XYSG	A	3
Polyvinyl chloride	A,A	1,2
Polyvinyl chloride acetate VYNW	A,A	1,3
Polyvinyl chloride acetate VYNS	A	3
Thermosetting materials		
Phenol-aniline-formaldehyde	A,B	4,5
Phenol-formaldehyde	A,B	3,5
Melamine-formaldehyde	C,B	1,5
Urea-formaldehyde	A,A	1,2

*Where the same resin had been tested in different laboratories, all the results are given to indicate the divergence of opinion on ratings. These ratings are listed under "Extent of Growth" with the sources listed in the same order under "Laboratory"; thus, for cellulose acetate, B,A,A under "Extent of Growth" followed by 1,2,5 under "Laboratory" means that NBS (1) rated the material B, British Ministry of Supply (2) rated the material A, and the General Electric Co. (5) rated the material A.

†Code: A no growth; B very slight or light growth; C moderate growth.

‡Code: 1 National Bureau of Standards;[3] 2 British Ministry of Supply;[4] 3 Boyce Thompson Institute;[5] 4 Naval Research Laboratory;[6] 5 General Electric Company.[8]

5.3 SUSCEPTIBILITY OF PLASTICIZERS AND OTHER COMPONENTS TO FUNGAL ATTACK

Components other than the pure resin constitute an important portion of a plastic material. In laminated thermosetting materials the ply is usually a cellulose material like linen, canvas, or paper, or an inorganic material like woven glass or asbestos. The susceptibility of the former, as well as the inertness of the latter, to fungal attack is well known. With molded thermosetting materials, the filler is usually a cellulosic material such as some type of wood flour, cut cotton cloth, or an inorganic material like asbestos fiber or mica. Here again the behavior of these materials to fungal attack is well known. That all wood flours are not equally susceptible has recently been demonstrated by the Boyce Thompson Institute.[5] Wood flock and walnut-shell flour proved more susceptible than soft-wood flour.

The situation with regard to thermoplastic materials is different. In these materials a wide variety of plasticizers is used. Many hundreds of compounds have been tried as plasticizers and some 150 materials which are presently in use are listed in the Plasticizers Chart of the *Plastics Catalog*.[7] Since all organic materials cannot be utilized to the same extent as a source of carbon by all fungi, it is to be expected that some plasticizers will be more resistant than others.

The data obtained for the susceptibility of plasticizers to fungal attack are presented in Table 2. The compounds are listed in the same order as found in the Plasticizers Chart, three general classes, Oils, Resin Plasticizers, and Miscellaneous, have been added.

These data can be used as a guide in the selection of resistant materials for plastic formulations. In many cases where a number of plasticizers can serve equally in imparting the required properties, one that is rated A or B would be preferred if greater fungal resistance is desired in the plastic. Including a plasticizer rated D in a formulation would render a plastic susceptible to attack. It is for this first purpose that all the specific plasticizers have been listed so that this information may receive the widest circulation.

In the pharmaceutical and nutritional fields, the relationship between physiological activity and chemical structure receives a good deal of study. In this manner, the importance of certain functional groups is discovered, and tailor-made molecules are synthesized for special purposes. The success of this method in the sulfa drug field is well known. Since the nutritional availability of various substrates to fungi is also a physiological function dependent probably on enzyme systems, in spite of the numerous genera of fungi involved, some correlation with structure should be apparent from a study of a sufficient number of compounds.

Study of the data with this latter purpose in mind leads to a number of conclusions. The striking susceptibility of fatty acid derivatives is easily discerned. Thus, all derivatives of lauric, oleic, ricinoleic, and stearic acids are attacked. In addition, natural oils like castor and cottonseed containing glyceryl esters of these acids are susceptible.

A sufficient number of aliphatic dicarboxylic acid derivatives have not as yet been tested, but the data available show that whereas [illegible] and adipic acid derivatives are resistant, the [illegible] acid derivatives

TABLE 2. Fungal susceptibility of various plasticizers.*

Name	Trade name	Extent of growth†	Laboratory‡
Abietic acid derivatives			
Abietic acid	....	A	4
Hydrogenated methyl abietate	Hercolyn	A,B	1,4
Aconitic acid derivatives			
Tri-n-butyl aconitate	....	C,A	1,4
Triethyl aconitate	....	B,A	1,4
Adipic acid derivatives			
Di-(1,3-dimethyl butyl) adipate	....	B	4
Di-(2-ethylhexyl) adipate	....	A	4
Azelaic acid derivatives			
Di-(ethylene glycol monobutyl ether) azelate	Dibutyl Cellosolve azelate	B	4
Di-(2-ethylhexyl) azelate	....	A	4
Benzoic acid derivatives			
Ethyl-o-benzoyl benzoate	Ketonene E	A	1
Benzyl benzoate	....	C	1
Chlorinated hydrocarbons			
Mixtures of			
chlorinated diphenyls	Arochlor 1242	A	4
chlorinated diphenyls	Arochlor 1248	A	4
chlorinated diphenyls	Arochlor 1254	B	4
chlorinated diphenyls	Arochlor 1262	A	4
chlorinated diphenyls	Arochlor 1268	B	4
chlorinated diphenyls	Arochlor 1270	A	4
chlorinated diphenyls	Arochlor 5460	A	4
Chlorinated paraffin	Chlorowax	A	4
Chlorinated paraffin	Cereclor	A	2
Citric acid derivatives			
Tri-n-butyl citrate	....	A,A	1,4
Triethyl citrate	....	A	1
Glycerol derivatives			
Glyceryl triacetate	Triacetin	C,C	1,4
Glycol derivatives			
Diethylene glycol ethyl ether acetate	Carbitol acetate	C,B	1,4
Diethylene glycol butyl ether acetate	Butyl Carbitol acetate	B	4
Diacetate of 2-nitro-2-methyl-1,3-propanediol	....	A	1
Dipropionate of 2-nitro-2-methyl-1,3-propanediol	....	A	1
Diethylene glycol dipropionate	KP-45	A	1
Triethylene glycol di-(2-ethylhexoate)	Flexol 3GO	A,A,A	1,3,4
Triethylene glycol di-(2-ethylbutyrate)	Flexol 3GH	A,A,A	1,3,4
Polyethylene glycol 200	....	A	4
Polyethylene glycol 300	....	A	4
Polyethylene glycol 400	....	A	4
Polyethylene glycol 1500	Carbowax 1500	A	4
Polyethylene glycol 6000	Carbowax 6000	A	4
Polyethylene glycol di-(2-ethylhexoate)	Flexol 4GO	A	2
Glycolic acid derivatives			
Ethyl phthalyl ethyl glycolate	Santicizer E-15	C	1
Methyl phthalyl ethyl glycolate	Santicizer M-17	B	1
Methyl phthalyl methyl glycolate	....	B	4
Butyl phthalyl butyl glycolate	Santicizer B-16	C,C,A	1,3,4
Lauric acid derivatives			
Butyl laurate	....	D	4
Ethylene glycol laurate	....	D	4
Ethylene glycol ethyl ether laurate	Cellosolve laurate	D	4
Diethylene glycol monolaurate	....	D	4
Diethylene glycol ethyl ether laurate	Carbitol laurate	D	4
Glyceryl laurate	....	D	4
Sorbitol laurate	....	D	4

*Where the same plasticizer has been tested in different laboratories, all the results obtained are listed under "Extent of Growth" with the sources listed in the same order as are "Laboratory."

†Code: A no growth; B very slight, or light growth; C moderate growth; D heavy and very heavy growth.

‡Code: 1 National Bureau of Standards;[1] 2 British Ministry of Supply;[4] 3 Boyce Thompson Institute;[5] 4 Naval Research Laboratory.[3]

TABLE 2. Fungal susceptibility of various plasticizers (continued).

Name	Trade name	Extent of growth†	Laboratory‡
Oleic acid derivatives			
Dibutyl ammonium oleate	....	D	4
Ethylene glycol methyl ether oleate	Methyl Cellosolve oleate	C	1
Nitrile from oleic and linoleic acids	NTD-181.5-B	D	3
Sorbitol oleate	....	D	4
Pentaerythritol derivatives			
Dipentaerythritol hexaacetate	....	A	1
Dipentaerythritol hexapropionate	....	B	1
Dipentaerythritol hexabutyrate	....	A	1
Pentaerythritol diacetate-dibutyrate	....	C	1
Pentaerythritol diacetate-dipropionate	....	C	1
Pentaerythritol monoacetate-tripropionate	....	B	1
Pentaerythritol triacetate-monopropionate	....	C	1
Pentaerythritol tripropionate-monomyristate	....	C	1
Pentaerythritol tetrabutyrate	....	C	1
Pentaerythritol tetrapropionate	....	C	1
Phosphoric acid derivatives			
Triethyl phosphate	....	A	1
Tributyl phosphate	....	A,A	1,4
Tri-(2-ethylhexyl) phosphate	Trioctylphosphate	A	3
Triphenyl phosphate	....	A	1
Tributoxyethyl phosphate	Tributyl Cellosolve phosphate	A	4
Tricresyl phosphate	Kronitex AA	A,A,A,A	1,2,3,4
Tri-(2-nitro-2-methylpropyl) phosphate	....	A	1
Diphenyl mono-(p-tert.-butylphenyl) phosphate	Dow Plasticizer 1	B	4
Monophenyl di-(p-tert.-butylphenyl) phosphate	Dow Plasticizer 2	A	1
Diphenyl mono-(o-chlorophenyl) phosphate	Dow Plasticizer 3	A	4
Diphenyl mono-o-xenyl phosphate	Dow Plasticizer 5	A,B	1,4
Di-o-xenyl monophenyl phosphate	Dow Plasticizer 6	A,A	1,4
Tri-(p-tert.-butylphenyl) phosphate	Dow Plasticizer 7	A,A	1,3
Tri-(o-chlorophenyl) phosphate	Dow Plasticizer 8	A	4
Tri-(o-xenyl) phosphate	Dow Plasticizer 9	A	1
Phthalic acid derivatives			
Dimethyl phthalate	....	A	1
Diethyl phthalate	....	A,A	1,4
Di-n-propyl phthalate	....	A	1
Di-isopropyl phthalate	....	A	1
Dibutyl phthalate	....	A,A,A	1,2,4
Di-isobutyl phthalate	....	A	1
Diamyl phthalate	....	C	1
Dihexyl phthalate	....	A	2
Dicapryl phthalate	....	A,B	1,4
Dioctyl phthalate	....	A	1
Di-(2-ethylhexyl) phthalate	Flexol DOP, Dioctyl phthalate	A,A,A	1,3,4
Dicyclohexyl phthalate	....	A	1
Dibenzyl phthalate	....	A,B,	1,4
Diphenyl phthalate	....	B	4
Dimethoxyethyl phthalate	Dimethyl Cellosolve phthalate; Methox	A	1
Diethoxyethyl phthalate	Di-Cellosolve phthalate; Ethox	A	1
Dibutoxyethyl phthalate	Dibutyl Cellosolve phthalate; Kronisol	A,A	1,3
Methyl-2-methyl-2-nitro-propyl phthalate	....	A	1
Ethyl-2-methyl-2-nitro-propyl phthalate	....	B	1
Butyl-2-methyl-2-nitro-propyl phthalate	....	A	1
Bis-(diethylene glycol ethyl ether) phthalate	Di-Carbitol phthalate	A	1
Resin plasticizers			
Glycol sebacate resin	Paraplex	D	1
Sebacic acid alkyd resin	Paraplex G-25	D,C	1,3
Sebacic acid alkyd resin	Paraplex RG-2	D	1
Sebacic acid alkyd resin	Paraplex RG-20	D	1
Sebacic acid alkyd resin	Paraplex X-100	D	3
Ester type alkyd resin	Duraplex C20LV	D	4
Silicone oil	Fluid #500	A	4

TABLE 2. Fungal susceptibility of various plasticizers (continued).

Name	Trade name	Extent of growth†	Laboratory‡
Ricinoleic acid derivatives			
Methyl acetyl ricinoleate	P-4	D	3
Butyl acetyl ricinoleate	....	D	1
Ethylene glycol methyl ether acetyl ricinoleate	Methyl Cellosolve acetyl ricinoleate	C	1
Glyceryl monoricinoleate	....	D	4
Sebacic acid derivatives			
Dimethyl sebacate	....	C	1
Dibutyl sebacate	....	C,C	1,4
Di-(1,3-dimethyl butyl) sebacate	....	B	4
Di-(2-ethylhexyl) sebacate	Dioctyl sebacate	C	4
Stearic acid derivatives			
Stearic acid	....	D	3
n-Butyl stearate	....	C	1
Cyclohexyl stearate	....	D	1
Butoxyethyl stearate	Butyl Cellosolve stearate	D,D	1,4
Diethylene glycol ethyl ether stearate	Carbitol stearate	D	4
Tetraethylene glycol monostearate	....	D	4
Tetraethylene glycol distearate	....	D	4
Succinic acid derivatives			
Diethyl succinate	....	A	4
Synthetic fatty acid derivative			
Fatty acid dimethyl amide	Plasticiser 35	D	4
Tartaric acid derivative			
Di-n-butyl tartrate	....	A	1
Toluenesulfonic acid derivatives			
Ethyl-p-toluenesulfonate	....	A	1
o-Cresyl-p-toluenesulfonate	Santicizer 10	A	1
o- and p-Toluene ethylsulfonamide	Santicizer 8	A	1
Tricarballylic acid derivatives			
Triethyl tricarballylate	....	B	1
Tri-n-butyl tricarballylate	....	B	1
Oils—natural and synthetic			
Tung oil	....	B	4
Castor oil	....	D,D,D	1,3,4
Cottonseed oil	....	D	4
Dehydrated castor oil	Isoline	D	3
Refined tall oil	Indusoil	D	3
Sulfonated oil	Naftolen R-510	A	4
Coal tar oil	....	A	4
Petroleum oil	....	A	4
Miscellaneous materials			
Diphenyl	....	A	1
Diamylnaphthalene	....	A,A	1,4
Diamylphenoxyethanol	....	A	4
Benzophenone	....	A	4
Methylamyldihexylcyclohexanone	Plasticiser C-24	A	4
Cyclohexyl lactate	....	A	1
Methylcyclohexyl oxalate	....	A	1
Diphenylsulphone	....	A	1
Triphenylguanidine	....	A	1
Triethanolamine dicaprylate	Plasticiser 8C	D	4

are susceptible. Thus, in this series also, a long carbon chain of ten atoms or more renders the derivative susceptible. The three aliphatic tricarboxylic acid derivatives listed, those of citric, aconitic, and tricarballylic acids, are seen to be resistant.

As long as the glycol and glycolic acid derivatives do not contain any aliphatic acids having chains of ten or more carbon atoms, the results show them to be resistant to fungal attack. Pentaerythritol esters are found to be fair to good in resistance.

The results obtained with the phthalic acid derivatives, many of which enjoy wide use, are consistent, and conclusively show that these derivatives are very resistant to fungal attack. Thus, the aliphatic esters ranging from dimethyl to dioctyl phthalate, and including the ester of the cyclic alcohol, cyclohexanol,

as well as the Cellosolve and Carbitol esters are all resistant. The phenyl and benzyl esters are also resistant. The phosphoric acid derivatives show a similar behavior. All the aliphatic and aromatic esters listed are resistant to fungal attack.

The resistance of the toluenesulfonic acid derivatives, as well as the resistance of the aromatic hydrocarbons, is also obvious. The only terpene derivatives investigated, those of abietic acid, were also found resistant.

Although the choice of both a resistant resin and a resistant plasticizer in a plastic are indicated, on the basis of present knowledge, it cannot be said that because components A and B are resistant, the combination of A and B is resistant. Experiments show that combinations of dioctyl phthalate with vinyl resins are more susceptible than either alone. However, the presence of small quantities of lubricant must be considered for it has been shown that the plasticizer-lubricant combination is more susceptible than either one alone.

Further investigation on mixtures of components such as resins, lubricants, and plasticizers should cast more light on these problems. However, it is generally acknowledged at the present time that the fungal resistance of a plastic can be estimated with some certainty if the susceptibility of the components which go to make it up is known. It is for this reason that data on plastics components are so valuable.

5.4 SUSCEPTIBILITY OF PLASTIC COMPOSITIONS TO FUNGAL ATTACK

Included in the vast array of items termed military matériel one finds many examples of plastics. Thus, items as varied as molded gun stocks, gun covers, aircraft windows, terminal boards in radio sets, machete sheaths, helmets, and belly tanks may be included. The resins on which these materials are based may indeed be similar, but the complete compositions of the final articles are often different. In this sense terminal boards are not merely phenol-formaldehyde resins, nor are gun covers merely polyvinyl chloride acetate resins. The terminal board ordinarily contains plies of fabric, or paper if it has been prepared from laminated stock, or it has filler added if it is a molded piece. In the same manner the vinyl esters have added plasticizers, lubricants, and stabilizers. If it is constantly kept in mind that commercial plastics as we know them are complex mixtures, the conflicting reports concerning tropical deterioration of certain plastics become more understandable. A polyvinyl chloride acetate insulation covering is not the same material as a polyvinyl chloride acetate coating on a raincoat, nor is a phenolic gun handle the same material as a phenolic tube socket.

Being aware of the fact that a plastic is a mixture of components, one might think that the first step would be to check all the components of plastics for fungal susceptibility and then make the plastics from resistant components. This approach is sound and has great merit. However, when plastic materials performed unsatisfactorily in the Southwest Pacific areas, there was no time to await results from such a long-range program. Instead many commercial materials were tested as is, and this section includes a summary of the results obtained.

In the usual case, the results reported were obtained on plastic samples that were neither sterilized nor cleaned in any special way. Up to 1946 there has been no demonstration of a method of sterilization of plastics that will prevent growth of contaminating organisms on the piece without altering the material. Ultraviolet exposure for a short period of time has been recommended but not yet tried. The effects of volatile fungicides on plastics have not been studied, although such treatments with methanolic vapor and chloropicrin have been suggested. With volatile fungicides, one has the disadvantage of eliminating identical control conditions unless the sample under test is similarly treated. Wet and dry heat sterilization is thought to be more deleterious in effect than the other agents mentioned. Ozone treatment brings up the possibility of chemical change. However, the fact that most of the above discussion on treatments for sterilization of plastics covers opinions rather than facts based on experimental evidence is indicative of the work that remains to be done on this problem.

On the basis of results reported by the Sperry Gyroscope Co.,[6] the Bakelite Corporation,[7] the Materials Laboratory of the New York Navy Yard,[8] the Signal Corps Laboratory at Fort Monmouth,[9-11] and the British Ministry of Supply,[12] certain conclusions may be drawn. With the laminated materials, although the phenol-formaldehyde, urea-formaldehyde, and melamine-formaldehyde resins are inert, paper and cloth render the materials easily susceptible to fungal growth at cut edges. Of course, if the resin surface is broken in any manner and the cloth exposed, fungus will grow there also. It is with this type of material that the use of suitable varnishes on cut edges has been suggested. Laminated materials that contain

glass cloth, mat, or asbestos cloth are quite resistant to fungal attack provided no susceptible sizing material like starch is on the cloth.

The resistance of molded pieces to fungal attack is much better than that of laminated materials. Where cut cotton rag has been incorporated, susceptibility is great. However, wood-flour-filled phenolics are not too susceptible to fungal attack, although in time they support a slight surface growth. The quality of the molded piece is very important in this case. Since molded pieces have no rough or cut edges, their increased resistance might be expected. Phenolics filled with glass, mica, and asbestos are very resistant to fungal attack. Molded plastics containing melamine-formaldehyde resins have perhaps a slight advantage over phenolic molding materials.

If resistant plasticizers, as well as no excessive amount of susceptible lubricants are used, thermoplastics are quite resistant. Thus, polystyrene, polymethylmethacrylate, polyethylene, and Nylon plastics, in which little or no plasticizers are used, are resistant to fungus. On the other hand, cellulose acetate as well as mixed esters of cellulose, ethyl cellulose, and polyvinyl materials in which large amounts of varied plasticizers are used pose a different problem. With these materials fungal resistance will vary from poor to excellent, dependent on the nature of the components in the plastic other than the resin. If proper precaution is taken to include only resistant components wherever feasible, the behavior of these materials under tropical conditions should be more satisfactory.

5.5 EFFECT OF FUNGAL GROWTH ON PROPERTIES OF PLASTICS

Since some properties of plastics are markedly influenced by moisture alone, it is in an attempt to observe changes in properties under conditions of fungal growth that the relative roles of moisture and fungi become interwoven. Especially in electric equipment, the change in properties introduced by moisture and fungus is detrimental to the performance of the equipment. The simple fact that fungi grow on the plastic is proof that the relative humidity of the surrounding atmosphere is at least 70 to 80 per cent, and probably considerably higher. In addition, any type of mold growth, however slight in quantity, acts as an agent for the condensation and entrenchment of further moisture. Thus, there may be an effect of fungus in addition to the effect of moisture on the properties of the plastic.

Aside from a very few cases where a cellulose filler has been attacked, or a very susceptible plasticizer has been removed with resulting brittleness, no data demonstrating permanent alteration of properties of plastics due to fungal growth have been made available. Lack of suitable control, as well as lack of work along this line, are probably responsible.

It has been the experience of many that it is not possible to keep an unsterilized plastic sample under high humidity without having fungal growth due to the contaminating organisms on the sample. The question of sterilization of the sample to avert such growth for control purposes has already been discussed. Another approach has been the use of an inert atmosphere such as that of nitrogen gas. Although it has been found that nitrogen gas stunts the growth of fungi, as yet it has not been demonstrated that such an atmosphere would completely inhibit growth of fungi. There is a great deal of experimental work now being done on the question of obtaining a good control.

5.6 ADDITION OF FUNGICIDES TO PLASTICS

Even though some plastic materials are fungus-resistant, they are not fungistatic. Thus, debris and external contaminants on the material can serve as a source of fungal growth. During World War II attempts were made to render susceptible plastics fungistatic by the use of fungicidal coatings. In an approach to the problem from another angle, fungicides were incorporated directly into plastics during their manufacture in an attempt to insure some degree of fungal resistance of the material without any subsequent treatment.

In all discussions about fungicides for plastics, it must be remembered that in many cases there may be no need for fungistatic plastics. When it has been definitely established that plastics made from the most resistant components are still unsatisfactory for certain uses under conditions prevailing in the tropics, it may be true that fungistatic plastics are necessary. However, even though the need is still debatable, preliminary experimental work on this problem has been under way to explore the possibilities of making fungistatic plastics so that they would be ready if needed.

In order for a fungicide to be effective in plastics, it should conform with the following requirements:

1. The compound should be compatible with the resin.

2. The compound should have low volatility so as

not to be lost during the molding operation.

3. It should be sufficiently insoluble to resist leaching by water.

4. The presence of the fungicide should have no significant effect on the physical properties of the plastic.

5. The fungicide should be chemically inert so that it is not altered by reaction with other components of the plastic mass with a corresponding loss in fungicidal activity.

6. Incorporation of the compound should not necessitate a drastic change in manufacture.

7. The compound should be effective for a sufficient length of time, preferably the service life of the material.

8. The compound should be nontoxic to the worker handling the material, or at least be relatively nonhazardous.

9. The final product should offer no health hazard, such as a skin irritant, on continued use by personnel.

At present it seems almost impossible to fulfill some of these requirements. For example, in order for the surface of the plastic to be fungistatic, an effective concentration of fungicide must always be present there. Presumably this requirement implies a constant loss of fungicide, the rate of which is dependent on its volatility as well as external conditions. From this it is evident that a fungicide should be effective in low concentration if the fungistatic property of the plastic is to have any appreciable life period. Preliminary work indicated that it was impossible to predict whether a given fungicide would function effectively in a given plastic system, and therefore experimentation in this field was necessarily of an empirical nature. In one investigation[8] phenolic plastics were prepared with fungicides incorporated directly in the material. All the materials prepared were sent to three different laboratories for test. In most cases the fungicide was used in concentrations of 0.25, 0.5, 0.75, 1.0, 1.5, and 2.0 per cent. In addition to the testing of the treated plastics, control samples of untreated plastics were included. In the compounding of molding resins the dry fungicide was added to the premix. Where fillers were included, two methods of treating the filler were used. In one case the paper or cloth was impregnated by immersion in a solution of the fungicide, and in the other case the fungicide was incorporated into the resin used to coat the filler.

On the basis of fungal resistance alone, the incorporation of salicylanilide was found to yield the best protected plastics. The compound is safe to handle, is compatible with the resins, has a vapor pressure low enough to prevent excessive losses during processing, and has a marked effect on the inhibition of fungal growth. Copper naphthenate was too disagreeable to work with, as well as fairly incompatible with the resins. The organic mercurials were a health hazard, and the chlorinated phenols were too volatile.

Subsequently, the same investigators determined the effects of the incorporation of salicylanilide on the physical properties of the plastics.[10] Tests were conducted on molded and laminated phenolic compounds having 2 per cent of salicylanilide incorporated during the process of manufacture. The laminated phenolics so prepared comprised two fabric-base grades and three paper-base grades, the untreated controls meeting the requirements of JAN-P-13 specification for grades EM-1 (FBG), EM-2 (FBE), E-5, E-4 (PBE), and M-1 (PBM). The molded phenolics made were those of which the untreated standard counterparts meet the requirements of JAN-P-14 specification for grades E-1 (CFG), M-3 (CFI-10), E-4 (MFE), and one grade of melamine-resin asbestos-cellulose compound. The materials were tested according to the JAN specification tests, and from an examination of the test data it was concluded that the addition of salicylanilide in 2 per cent concentration had little or no effect on the physical properties of the molded or laminated materials studied.

Experimental work on fungistatic plastics has also been carried out at the Boyce Thompson Institute.[2] Here, too, disappointing results were obtained with phenolic cloth laminates. The cloth was impregnated with 2 per cent of the fungicide, and then made into laminates with a phenolic resin. The following fungicides were tried: dihydroxydichlorodiphenylmethane (Preventol GD), U. S. Rubber No. 3, Intracol, Hydrocide 10X Special (quaternary ammonium compound), copper naphthenate, Shirlan extra (salicylanilide), Milban (zinc dimethyldithiocarbamate) and Merck 242 (tetrabrom-o-cresol). In no case were the treated plastics fungistatic. In connection with this study it was found that when [illegible]-sized duck was used in the laminate, the plastic was more susceptible than when de-sized duck was used. Paper-base laminates were easier to protect than cloth-base [illegible]. When phenolic-glass laminates are [illegible] fungal growth, the sizing on the glass cloth [illegible].

The incorporation of fungicides [illegible] chloride-acetate copolymer was also studied. [illegible] fungicides were incorporated into the mix in 2 per cent concentration. Preventol, copper naphth[illegible] Hydrocide

10X Special, and Milban gave some protection to the material which was plasticized with tricresyl phosphate and methyl acetyl ricinoleate. Milban seemed to be the best fungicide from the standpoint of soil-burial tests. After hanging for 100 days in a tropical room, the plastics treated with fungicides were less overgrown by fungi than the control sample. Thus, fungicides in polyvinyl materials do have some beneficial effect in 2 per cent concentration, and possibly higher concentrations would afford better protection.

A considerable amount of experimental work has also been done on the incorporation of mercurial fungicides in thermoplastics.[14] Concentrated solutions of phenyl mercuric fungicides in plasticizers were used such that the final concentration of the fungicide in the plastic varied from 0.25 to 2.0 per cent. In this work the fungicides had to be carefully purified to be effective, and when such fungicides were used they were not easily removed by heating or leaching. The different phenyl mercuric derivatives used were: phenyl mercuric acetate, phenyl mercuric phthalate, phenyl mercuric salicylate, phenyl mercuric stearate, and phenyl mercuric o-benzoic sulfimide. Plasticizers that are compatible with these fungicides are dibutyl tartrate, dimethyl phthalate, Santicizer M-17, triacetin, triphenyl phosphate, and tricresyl phosphate.

Using one or more of the above fungicides it was found that a number of plastics could be made fungistatic in that they passed the Signal Corps Specification 71-2202A using *Aspergillus niger*. Tests with a spore mixture were also conducted. Among the cellulose plastics, cellulose acetate plasticized with Santicizer M-17, ethylcellulose plasticized with Santicizer M-17 or tricresyl phosphate, and cellulose nitrate plasticized with tricresyl phosphate have been protected. Polystyrene as well as contact laminating resins of the styrene copolymer type have also been rendered fungistatic by the use of 0.5 to 1.0 per cent of a phenyl mercurial fungicide such as phenyl mercuric phthalate or salicylate. Vinyl copolymers are also rendered fungistatic by the incorporation of less than 1 per cent of phenyl mercuric salicylate.

Phenolic resins are much more difficult to protect, possibly due to the presence of formaldehyde which reacts with the mercurial fungicide at high temperatures. A phenol-formaldehyde, cellulose-filled plastic was made fungistatic by the addition of 2 per cent phenyl mercuric phthalate. In some cases 1 per cent fungicide was sufficient. However, from an overall picture it is the consensus of opinion that phenolic plastics, especially laminates, are the most difficult to protect, and results are still inconsistent. Urea-formaldehyde molding powders do not lend themselves readily to the incorporation of fungicides.

The problem as to health hazard has also been investigated to some extent. There has been some criticism of mercurial fungicides because of their toxicity to human beings. In a report describing tests to determine the irritant and sensitization properties of fungicides in a polyvinyl plastic, it was found that the mercurials caused moderate to severe irritation.[15] However, proponents of these fungicides claim that toxicity is not a factor in the low concentrations in which these materials are used.

No experimental work has been done on the problem as to whether the fungicide exists unaltered in the plastic after manufacture. Elementary analysis for such a constituent as mercury, nitrogen, or sulfur means little because this would not indicate whether further reaction of the compound with components of the plastic had occurred. The only indication that the fungicide does exist unaltered, at least in thermoplastic materials, is the increased fungal resistance of these materials.

In summarizing, it can be said that a great deal of work remains to be done. As of today no treatment is known that will inhibit growth of fungi on all plastics, and if this is the desired goal, the problem is far from solved. However, in a general way, thermoplastic materials can be made more resistant to fungi by incorporating fungicides in the plastic. The situation with phenolic materials is more obscure, and at present the incorporation of fungicides in susceptible laminates does not alter their fungal susceptibility to any appreciable extent.

Chapter 6

TROPICAL DETERIORATION OF PHOTOGRAPHIC EQUIPMENT AND SUPPLIES

6.1 MAGNITUDE OF THE PROBLEM

To illustrate the effects of tropical environments on photographic equipment and supplies the following are quoted from information made available to the Tropical Deterioration Administrative Committee [TDAC].[a]

From Signal Corps Photographer, New Guinea, July 5, 1944.

One item, perhaps trivial, is the breakdown and stripping of the leather covering on speed graphics . . . , once the moisture-proof paper (of film wrapper) is opened, it can't be reused. This is a problem in some instances, because moisture and fungus sometimes attack the gelatin between the time of exposure and time of being transported to the lab for processing... Cut film is a tough problem because it isn't tropically packed enough to prevent the formation of fungus ... Blue and spider fungus nourished by moisture sometimes forms on the lenses and between the elements.

From Signal Corps Photographer, India, July 24, 1944.

One of our boys has just returned from Burma, where he spent four months taking movies around Mytikyina, Mogaung, etc. He has presented me with a list of the difficulties encountered up there. It seems that moisture is the chief demon as regards photographic materials up in that neck of the woods. . . . The leather on the back of the camera (where the holders are inserted) swells up with the result that no holders can be fitted in. The only remedy the boys find for this trouble is to remove all the leather from the back of the camera ... As for the flash equipment—it is practically undependable. The points corrode, batteries simply fall apart in the dampness.

The cable release socket should be provided with a screw type plug otherwise moisture enters the shutter through the opening and raises havoc with it . . . One brand of 35 mm. cartridges swells so badly that they cannot be loaded in the Leica. For any photography in jungle country only the highest speed emulsions should be issued because there is not enough light for the use of Plus-X or Panatomic-X.

Film gives a great deal of trouble and paper as well. The cut film swells and cannot be slid into the tracks of the holder —therefore, it must be trimmed on the cutter every time a photographer loads up. The film packs are worthless because when one goes to pull a tab out he pulls out five or six films which have stuck together inside the pack . . .

In addition to the above quotations there were also contained in these letter excerpts many comments on the unserviceability of particular makes of cameras. These are omitted so as not to refer to specific manufactures, but included in them were unsatisfactory reports on fungus attack and short life of bellows, collection of moisture and rusting of metal shutters, pinholing of focal plane shutters, corrosion of metal parts, and fungus attack of lenses.

It is understandable that it is important and necessary to have photographic equipment and supplies which will be satisfactory under any climatic conditions. This has been stated[1] in OSRD Report 6218.[b]

Some insight as to the magnitude and potential economic significance of tropical deterioration as it concerns film alone is gained when it is realized that the estimated film consumption by the Armed Forces for 1945 (based on WPB Press Release 7060, January 2, 1945, for the first quarter of 1945), was some 60 million sq ft of X-ray film, almost 100 million sq ft of Aero film and some 500 million lin ft of 16-mm movie film. In the field it was not uncommon to process 35,000 prints of Aero negatives in a single day.

6.2 NATURE OF THE PROBLEM

The degradation of the major consumable supplies, film and paper, under tropical conditions is largely due to the fact that gelatin, the foundation of all sensitized materials, is a nutrient for fungi and is highly subject to the influences of moisture and high temperature. An obvious solution to these problems was the use of some other material, which would be immune to attack by fungus and which would not be unduly affected by moisture and high temperatures. This, however, would have involved the development of a completely new art of sensitizing the new film and such a development would not have been compatible with the urgency of the problem and the necessity for quick solutions.

The problems in deterioration of equipment (cameras) were of three general categories: (1) problems

[a]The quotations are taken from letter excerpts which were sent to TDAC by the Director of the Pictorial Engineering Research Laboratory, Signal Corps Photographic Center as evidence that real problems did exist with reference to these materials and in support of a request that the Subcommittee on Photographic Equipment and Supplies be organized.

[b]Unless otherwise indicated the remainder of this chapter is organized from and based upon information contained in this report.

concerning the deterioration of lenses, (2) problems concerning the deterioration of exteriors of the equipment, and (3) problems concerning the interiors of the equipment, mechanical parts, etc. The problems of lens deterioration closely parallel those which pertain to optical instruments such as binoculars and which are discussed in Chapter 5. Problems pertaining to the deterioration of exteriors of equipment were among those which could be most readily prevented. The commonly used materials such as wood, leather, felt, cork, and glues, all of which are highly susceptible to fungus attack, could either be replaced by a substitute material which was immune to fungus attack or they could be omitted from the finished item when feasible. Protection could be accorded to equipment which was already finished and in use by the application of a protective finish or coating to serve as a moisture barrier and to which fungicides could be added. The problems which concerned the interiors of equipment and which involved mechanical parts were less readily solved and their solution could hope to be achieved to only a limited extent. These problems were mostly those of corrosion and were the result of the inability to seal the susceptible portions completely against the ingress of moisture.

The instances of faulty packaging of photographic equipment and supplies were strongly emphasized during the early stages of World War II. Certainly with photographic materials and the manner in which they were affected by tropical conditions, packaging problems were as severe as with any other category of supplies. If such materials were packaged poorly and were subjected to severe handling in addition to the moisture and heat of the tropics, it could only be expected that a high percentage of them would arrive in a useless condition. Protection could only be given to certain materials, e.g., film, by proper packaging and it was not to be expected that preventive treatments of other materials would in any sense be a substitute for good packaging. Proper packaging would still be necessary, in spite of preventive treatments, to insure that equipment and supplies would arrive in the theater in a usable condition. The principles of proper packaging were common knowledge and correction of packaging faults was largely a matter of implementation; certain packaging problems nevertheless demanded further consideration.

6.3 ORGANIZATION OF THE PROGRAM

The program on prevention of deterioration of photographic materials was conducted by the TDAC Subcommittee on Photographic Equipment and Supplies. Among the studies which were made by the subcommittee were those which were authorized by Project AN-14.2, "Deterioration of Photographic and X-ray Film due to Fungus, Insects, and Moisture." The emphasis was placed on reviewing information which was readily available, and when additional studies were undertaken they were performed either by the members of the subcommittee or by contractors who were conducting other studies for TDAC. The program was organized under two main headings, (1) problems related to consumable supplies (film, etc.) and (2) problems related to nonconsumable supplies (cameras, etc.). Termination of World War II prevented the complete solution of all problems; the extent to which they were completed is given in the following summary.

6.4 PROBLEMS RELATED TO CONSUMABLE SUPPLIES

6.4.1 Gelatin Filters

Among the problems related to consumable supplies were those which concerned gelatin filters. The following discussion concerning gelatin filters is taken directly from the subcommittee report[7] referred to previously.

High atmospheric moisture causes the filters to swell and to become tacky. In such condition they are very susceptible to fingerprints and handling marks. They often stick to the paper envelope in which they are shipped or come out of the envelope with a replica of the paper surface embossed in the gelatin surface. Moist or swollen gelatin is an excellent nutrient for fungi and bacteria, and although an unmarred filter may be successfully put into use, it may be only a few days before the filter becomes cloudy or spotted with fungus growth. Such growth as well as surface markings render the filter optically unfit for use.

The investigations on this subject were confined to the development of:

1. Moisture-proof and/or fungus-proof lacquer coatings for existing gelatin filters.

2. Filters made with nongelatin substitute materials which would not support fungus growth.

It was learned that the manufacturers of filters had adopted the principle that a moisture-proof lacquer with or without fungicides should be satisfactory and that experiments were already under way in this study. It has not yet been determined that a fungicide is

necessary, inasmuch as a moisture-proof, nonnutrient lacquer may suffice. The time has been too short to make a full investigation of the possible effects of the lacquers on printing operations and particularly on the transmission curve of filters where color compensation may be involved in reproducing color prints. Preliminary reports from the field indicate that lacquered filters represent a definite improvement as far as retarding the swelling of gelatin and the prevention of fungus growth are concerned.

Filters cut from large lacquered sheets are vulnerable to attack and infection by fungi along the cut edges. If left in contact with water the lacquer coat tends to peel. Only meager information was obtained on the names of fungicides used in lacquering experiments, but in general they were compounds known to have good fungicidal properties.

As a result of this activity it seems that the application of lacquer-dipped coatings offers an immediate alleviation of the problem and it is recommended that filter manufacturers be encouraged to continue the work. It is apparent that lacquering technique is needed to cover the edges of the filter. It is also recommended that consideration be given to a specification requiring that filters be packed in heat-sealed foil envelopes to insure keeping until they are put into use.

The substitution for gelatin of nonnutrient materials such as cellulose acetate, Lucite, or some of the recently developed polymers could not be undertaken due to existing conditions, but such materials merit consideration in any long-term program that may be undertaken.

6.4.2 Containers for Chemicals

Attention was also directed to problems concerning containers for chemicals. Reports and data from the field revealed the numerous shortcomings of standard cardboard or metal containers. These would not exclude moisture nor withstand rough handling. For chemicals which do not require a glass container a rip-strip soldered can with lithographed labels and an external application of corrosion-resistant lacquer had been found satisfactory in tropical areas. The chemicals can be packed loosely in the cans or in cartons which are placed in the cans. The corrosion-resistant lacquer prevents or retards corrosion and subsequent exposure of the contents to moisture.

Paper labels have generally proved unsatisfactory for tropical use since they would become detached or would be destroyed partially or entirely by insect or fungus attack; this was a particular problem with glass containers. After considerations of alternative methods of labeling glass and the cost of each method, it was recommended that labels made with ceramic pigments (such as those used in the soft drink trade) would probably be most satisfactory; however, the use of tropical lacquers for this purpose should be investigated further, since the use of lacquers would possibly be less expensive and more convenient where a small number of any one type of label was involved.

6.4.3 Containers for Photographic Film and Paper

Many types of problems were involved in the considerations of containers for photographic film and paper. These are presented in detail in OSRD Report 6218.[1] The requirements that packages of these materials be waterproof and moisture-resistant and that they be able to withstand rough handling and prolonged storage in the tropics are paramount. The physical nature and form of the packages were shown to be important from the viewpoint of susceptibility to damage and convenience in storage. A very important feature which deserved attention was that some provision be made for containers and wrapping materials which could be used in the field after the original package was opened and partly used.

Reports were received that heat-sealed foil and x-crepe wrapping were satisfactory for keeping films dry during shipment and storage in tropical climates. With such packaging, film and paper would usually be kept beyond its expiration date. Other aspects of overseas packaging were also satisfactory. It was learned that the Eastman Kodak Company had undertaken a broad experimental program on packaging to obtain further improvements for application to materials sent to the tropics.

Information gained from this program was made available to the Subcommittee on Photographic Equipment and Supplies and is reported in OSRD Report 6218.[1] Packaging principles which were established for photographic equipment and supplies as the result of these investigations are given in the report as follows.

1. The individual unit of sensitized product must receive satisfactory moisture-vapor and liquid-water protection by the use of a packaging material or combination of materials which will permit rough handling.

2. A satisfactory package is one which will withstand three months' keeping at 100 F and 90 to 95 per cent RH without permitting a relative humidity change in the product greater than 10 per cent, that is, material originally in equilibrium with 50 per cent RH shall be in equilibrium with a relative humidity not exceeding 60 per cent RH after such storage.

3. Complete moisture-vapor protection can be attained only with the use of a solid sheet of metal which can be completely sealed. Other materials, sealed or unsealed, can offer complete protection to liquid-water leakage and various degrees of moisture-vapor leakage but none offer complete moisture-vapor protection.

4. Certain boxboard materials are preferably used in such a manner as not to be included inside the hermetically sealed packages. Such usage prevents a possible moisture reservoir as well as possible contaminators from being in the position of potential troublemakers.

There are also given in OSRD Report 6218[1] descriptions of the types of packaging which have been applied in accordance with the above principles to the following materials: sheet film, both portrait and X-ray; film packs; amateur black and white roll films; color roll films; amateur and professional motion picture film in rolls; amateur motion picture film in magazine; gun camera refills; aerial films; dental X-ray films; papers.

The foregoing paragraphs indicate that the problem of packing for overseas shipment was remedied to a large extent within the time that innovations could be put to practical use. There still remained, however, the need of some means of protecting films and papers after the overseas packaging had been removed. Modification of packs in use to allow resealing did not appear to be possible. It was suggested that separate envelopes be included in a package for rewrapping portions of the pack which were not used immediately. An alternate suggestion was made that an auxiliary wrapper, consisting of an envelope with an efficient type of fold, be used in conjunction with the overseas wrapper; this would then be in place after the overseas wrapper was broken. An obvious remedy to this problem would be to employ unit packaging of films and papers wherever possible, and with the proper materials, protection could be given to individual items until they were used. It is conceivable that the expense which might be involved in this would be prohibitive but the subcommittee recommended that work be continued on this aspect of the packaging of films and papers.

6.4.4 Deterioration of Photographic Film

In October 1943 the deterioration of developed photographic film was briefly described in the Australian report of the New Guinea Science Mission which stated that mold grew on films after development and caused spotting in prints made from such films. No other field reports on this subject were brought to the attention of TDAC until December 1944 and January 1945 when reports from members of the Panama Science Mission indicated that the problem was one of some concern to the Photographic Laboratory of Albrook Field.[6]

These observations along with others were also cited in OSRD Report 5685.[2] Attention was further directed to the problem in March 1945 by an Army request for investigation of possible protective measures for processed film. The need for these was indicated by informal reports made to the Maintenance Division, Headquarters, Army Service Forces. As indicated previously, this project was assigned to the Subcommittee on Photographic Equipment and Supplies.

From a military view the principal reasons for which it is desirable to prevent deterioration of developed film are that negatives constitute important historical records of units, campaigns, etc. For individual medical records X-ray files are of equal importance. Frequently, if a negative is damaged, but still usable, much time and trouble is expended before a suitable print is obtained from it. It may be impossible to obtain satisfactory enlargements from such negatives. Whenever it is necessary to store developed films in the tropics these problems are encountered unless facilities for control of both moisture (humidity) and temperature are available. The problem is no doubt aggravated by the conventional and perhaps necessary practice of storage in envelopes with little or no chance for air circulation around the film. With long-time storage it is not difficult to visualize extreme fungus attack in which the gelatin is badly etched. Without adequate storage conditions in the tropics, important photographic records could only be kept free from fungus attack by constant inspection and attention. This has been indicated by officers who have returned from Pacific areas.[7]

An interesting feature of some developed films which are attacked by fungi is that they develop blue

[6]Personal correspondence from F. A. Borgheim, Jr., to Gustavus J. Esselen concerning the problem and cooperation with Air Force personnel in preliminary investigations.

spots in the area of the mycelium. The blue spots are confined to the back of the film and, further, to those types on which a blue antihalation dye had been used. It was suggested by Barghoorn (personal correspondence) in Panama that the dye is sensitive to pH changes and under the influence of metabolic products of fungi the color reaction was produced. Alternate suggestions in explanation of the color reaction have been made.[1,2] These indicate that after the developing bath, when the blue dye is reduced to a colorless form by the action of sulphite, the colorless form of the dye is not entirely removed by washing, and with presence of fungus growth it is reoxidized to the color state. However, Barghoorn indicated (correspondence) that if film is developed in pyro developer the spots do not appear. Also, it has been stated[3] that the color can be produced by application of an acid. It is interesting in this connection that Barghoorn observed (correspondence) that a species of Penicillium was capable of extracting the pigment and concentrating it in the blue form in spores and hyphae. Further investigation seems to be necessary in order to determine what, if any, relationship exists between the suggested pH reaction and the oxidation-reduction reaction in producing this color spotting. This phase of the problem is not of primary importance, but these matters should be clarified in order to achieve a complete understanding of the situation.

Among the treatments which have been used in the field to eliminate fungus spotting of developed film is the use of Merthiosal (0.1 per cent) dissolved in a mixture of acetone, ethyl alcohol, and propyl alcohol and applied to the film. In the reported trial this was applied to Kodachrome movie film;[4] in addition the film reels and cases were painted with Merthiosaled paint. This treatment proved to be very effective in preventing fungus growth. OSRD Report 6218[5] indicates that preliminary reports were brought to the attention of the Subcommittee on Photographic Equipment and Supplies that some manufacturers were conducting experiments to incorporate a fungicide in emulsion at the time of manufacture, but it was difficult to find a compound that would not affect the photographic properties of the emulsion and at the same time would not wash out during the processing. Another approach which had received some investigation concerned the use of a fungicidal lacquer. In investigations arranged by the subcommittee on this problem, various fungicides were applied in aqueous solution to the developed film. These are reported in OSRD Report [illegible][6] and reference is made to them in OSRD Report 6218.[5]

In the tests referred to in the preceding paragraph, the majority of the treated films were exposed in the tropical house, but some petri dish tests were made. The observations which were made included the presence or absence of fungus growth and the degree to which softening of the emulsion occurred. Certain experimental treatments, even though they prevented the growth of fungi, caused a softening of the emulsion. After prolonged exposure, certain treatments which were initially satisfactory permitted fungus growth, or caused a tacky or soft emulsion, or both. The consistency of performance was considered in evaluating the efficacy of the various treatments. The end of World War II prevented the completion of studies underway, but several promising leads were obtained.

The most satisfactory compound in these experiments was a mixture of high molecular alkyl-dimethyl-benzyl-ammonium chlorides which is marketed under the trade name of Roccal. The commercial solution contains 10 per cent of the active compounds and the dilutions indicated were made of the commercial preparation. In petri dish tests, which are far more rigorous than tropical house tests, a dilution of 1/100 applied to film was sufficient to keep it free from fungus for a period of at least two weeks, the period of the test. At the end of that time the emulsion remained hard. In a tropical house test lasting two weeks all samples of a dilution series ranging from 0.1 to 100 per cent remained free of fungus while uniform growth was present on both sides of untreated control samples. No undue softening of the emulsion occurred in any of the treated samples, except in the samples treated with the full strength solution which were slightly tacky. One report from a film manufacturer who performed functional tests on samples treated with a 1/10 dilution indicated that no undesirable effect was produced by the treatment.

Among the other treatments which showed promise in these tests were the mercurial fungicides of Merthiolate and Semesan. Mercury derivatives may be toxic to personnel and they are potential darkroom contaminants. Since safer materials seem to be more promising, further investigation of the effectiveness of mercury compounds as fungicides to be applied to developed film was not recommended. In this connection, consideration was given to the overall effects of Merthiolate used as a fungicide on photographic materials. Extensive use has been made of this compound in the Pacific areas, chiefly in lacquers for fungusproofing cameras. Experiments have shown that film can be fogged by Merthiolate, but tests in

which Merthiolate-treated parts did not come in contact with film were negative. It is probable that a cautious use of Merthiolate-doped lacquers would be practical, if application were restricted to those parts such as lens barrel, cone, and external surfaces which do not come in contact with the film.

One other promising suggestion has resulted from the exposures of experimentally treated film. Nylon dissolved in propanol did not prevent fungus growth, but it did prevent softening of the emulsion, thus indicating that it serves as a good moisture barrier. It is conceivable that superior performance would be obtained if a suitable fungicide such as Roccal could be applied in a moisture-proof coating such as Nylon, and this possibility deserves further exploration.

The possibility of overcoming the problems of fungus growth of developed film by improved storage envelopes is also considered in OSRD Report 6218.[1] It was suggested that improvement can be made by the use of fungicidally treated paper or by the use of extruded tubes of thin plastic material which would be relatively resistant to fungus and be moisture-vapor proof.

Also given in OSRD Report 6218[1] are brief directions for the cleaning and restoration of fungus-fouled negatives so as to enable them to be used with improved results.

6.5 PROBLEMS RELATED TO NONCONSUMABLE SUPPLIES

The classes of deterioration of equipment such as cameras were previously indicated (Section 6.2) as (1) deterioration of lenses, (2) deterioration of exteriors of equipment, and (3) deterioration of interiors of equipment, mechanical parts, etc. As with other materials, the deterioration is the result of the effect of moisture and fungus, or both, and therefore no new fundamentals are introduced. OSRD Report 6218[1] summarizes in detail the nature of all these effects and enumerates the most feasible methods for protection of cameras and other equipment.

6.5.1 Protection of Lenses

Fundamentally, the reasons for the deterioration of lenses in cameras are those which are given in Chapter 3 in the discussions concerning optical instruments. These problems in all sorts of equipment employing optical systems are closely parallel, except possibly in remedial and preventive treatments, where limitations will be imposed by the nature of the equipment, its design, and use. It would be expected, therefore, that fungus and moisture would affect all lenses similarly, and experience has shown this to be the case. The fungicides Merthiolate (Merthiosal), Cresatin, and fenchyl thiocyanoacetate have been used to prevent fungus development in the optical parts of cameras. Of these, Merthiolate and fenchyl thiocyanoacetate have possibly been more widely used. Both of these would seem to be more easily applied than Cresatin capsules which have been used for binoculars, primarily because of the space problems between lenses where the need for treatment is the greatest. Merthiolate can be applied in a 0.2 per cent solution in a flat black optical lacquer to lens flanges and the inside of lens barrels in an attempt to cover all proximate parts without getting the mixture on the lenses themselves. Fenchyl thiocyanoacetate can be applied in the Carbowax mixture, given in Chapter 3, to screw threads as well as in a lacquer to other internal surfaces.

6.5.2 Deterioration of Camera Exteriors

The nature of the deterioration of exteriors of cameras and other equipment by moisture and fungus depends on the nature of the construction and the finish. To mention a few such effects—wooden portions may have joints loosened and support fungus growth; leather will mold and peel off wooden or metal cases; aluminum and other metals will corrode; and, bellows will deteriorate and develop pinholes. Carrying cases will also be affected by moisture and fungus since fabrics, felt, cork, etc., used in such carrying cases, are susceptible to deterioration and in addition to the deterioration of the cases themselves, more severe conditions result for equipment stored in such cases. In many cases performance of equipment has been improved by stripping unessential finishing items from the equipment or by substituting for them less susceptible materials. Improved performance also resulted from applications of fungicidal lacquers and varnishes to such materials which could be protected in this manner. In addition to such procedures, improved maintenance and storage conditions could vastly lengthen the service life of equipment. Maintenance and storage procedures will be discussed in a later section.

6.5.3 Deterioration of Camera Interiors

Because of the fact that cameras and other photographic equipment are of unsealed construction, deterioration of internal parts and components is little different from deterioration of exteriors except for the

fact that mechanical and functional parts are involved. Except for a certain few parts, one point in contrast between external and internal metal parts, particularly in aircraft cameras, is that external parts usually have a baked protective finish, whereas such a finish or plating is not compatible with the functional operation of the inner parts. Therefore, rust preventives and lubricants must be relied on to maintain the working parts in good condition.

No attempt is made here to cite the numerous difficulties which result from corrosion of the various parts of aircraft and ground cameras. OSRD Report 6218[1] thoroughly analyzes the effects of corrosion of susceptible parts. In aircraft cameras corrosion can affect the camera drive, film magazine, and many parts of the complex shutter mechanism. In ground cameras shutter mechanisms can be similarly affected, as well as the focusing mechanism, whether it is of the helical screw type or the rack-and-pinion type. In any camera, of course, lens screw threads may corrode so that it is impossible to remove the lens for replacement or cleaning. The only safe method of combatting these potential difficulties is by frequent inspection and maintenance (lubrication and the use of rust preventives); this is called for despite the adequacy of storage facilities. Lacquers can be used to advantage on metal parts which are not working surfaces.

6.5.4 Storage Conditions

The basic preventive which can be applied to protection of photographic equipment is dry storage conditions. Photo equipment undergoes little if any deterioration while in use. Under certain operating conditions, of course, such storage facilities are out of the question, but in more or less established bases they are possible. Essentially they are nothing more than a hot room or dry locker; the size can be varied with the need, but they should be no larger than necessary to store the equipment. In general, the room should be as airtight as possible with an adjustable vent and a heat source such as electric lamps or a heater with blower attachment. The floor should be elevated from the ground to provide for circulation below. Care must be taken that air circulates in and around the equipment and no air traps occur. Such storage facilities coupled with an active inspection and maintenance program should eliminate many difficulties in camera deterioration.

6.5.5 Improvements in Design

Fundamental progress can be achieved in reducing deterioration of equipment under tropical conditions by improvement of design and construction. The following recommendations for future design have been included in OSRD Report 6218.[1]

It has been stated that little of the photographic equipment used by the Armed Forces was designed for the abuse and for the extremes of climate and handling which it had to withstand. This fact is absolutely true and it is the reason why so much trouble was experienced with ground photographic equipment in the tropics. Hand cameras and accessory equipment used by the Army and Navy photographic personnel remained the lightly built, difficult to repair, commercial instruments that will not stand up under war conditions.

Camera equipment for war should be designed to permit quick disassembly. The mechanism should be easily accessible, through inspection plates, making it unnecessary to tear down a unit to lubricate or inspect it. All major components should be interchangeable for easy replacement in the field. It should be possible, for instance, to remove a focal-plane shutter, as a complete unit, and slip another one in place in a couple of minutes. Between-the-lens shutters should be sturdy and interchangeable.

The entire camera should be constructed of metal with a noncorrosive finish and of weather-resistant properties. Range finders and flash sockets should be built in and protected from rain or spray. Making these accessories integral with the camera also eliminates the possibility of their loss, which would immediately render camera operation incomplete. Leather or fabric should be eliminated from the military camera.

Controls should be oversize and sturdy. Wind and trip action, especially in cameras having both between-the-lens and focal-plane shutters, should be made foolproof by interlocking mechanisms.

Most important of all, cameras particularly, and other photographic equipment to a lesser extent, should be designed to come apart in a matter of minutes to permit quick repairs. Rifle construction is not impossible in a combat camera and it is highly recommended that this be kept in mind in future designs. An infantry man automatically takes his gun apart for cleaning at frequent intervals. There is no reason why the combat photographer's camera cannot be built with the same idea in mind. The design should be such that it would be impossible to reassemble the camera incorrectly. This can be done by

keying the components so they will fit only one way.

It would be a great help to the camera manufacturer as well as to the Army and Navy experimental laboratories if all captured enemy photographic equipment were submitted to them for engineering study as quickly as possible. Many excellent features have been found in the German and Japanese camera models of World War II that could have been used to advantage by American designers.

Regardless of the improvement that can be made in design, it will probably always be necessary to store the equipment for periods and to arrange for maintenance of a sort. As a result of new design and improved materials a superior degree of resistance can be imparted to a camera or other item of equipment, but even with this there would be a limit beyond which undesirable effects would result. With fewer and simpler maintenance procedures and problems it should be relatively easy to instruct personnel in the details and their importance. Innovation of design, together with the use of ideal storage conditions and adherence to a rigid maintenance program will considerably reduce or even eliminate tropical deterioration of photographic equipment.

Chapter 7

TROPICAL DETERIORATION OF ELECTRIC AND ELECTRONIC EQUIPMENT

7.1 STATEMENT OF THE PROBLEM

Most of the reports which discuss the tropical deterioration of electric and electronic equipment have indicated that moisture is a prime agent of deterioration. High and fluctuating temperatures and humidities result in the ingress of water vapor with subsequent condensation and deleterious effects in mechanical and electrical properties of materials. Absorption of moisture lowers resistance, films of water cause surface leakage, and absorption within a condenser or a coil can bring about serious alterations in the electrical constants of a circuit.

Fungi are also important agents of deterioration in electric and electronic equipment. Hyphal strands of surface-growing fungi can introduce leakage paths which reduce insulation resistance and establish couples which promote electrolytic corrosion. A coating of mold encourages the formation of a water film over surfaces and furnishes loci for droplet condensation. Moldy surfaces dry slowly because air diffusion is retarded. Moisture retention by surface mold encourages corrosion of metal parts as do organic acids which are produced in the metabolic activity of the fungi. Further, prolonged exposure to actively growing fungi results in chemical breakdown of finishes and coverings.

Reports of the Naval Research Laboratory[1] and the British Ministry of Supply[2] are representative of those which discuss these factors. The subject has also been brought before the general public by means of articles which have appeared in technical journals.[3,4] With the book, *This is Serious — Tropicalization*,[5] the Signal Corps directed the attention of manufacturers of Signal Corps equipment to the problems in order that the level of performance of equipment in the tropics would be improved.

7.2 REMEDIES APPLIED

It is probable that no item of electric and electronic equipment was immune to the effects of tropical conditions. To be sure, many items were designed for continuous use and as a general rule little difficulty was encountered with such equipment while in actual operation, since the increased temperature and the resulting lower relative humidity did not permit moisture effects nor the growth of microorganisms. However, these factors did not guarantee immunity from tropical effects during periods of transit and storage. Improved methods of packaging were therefore necessary for electric and electronic equipment as well as all other types. This was but one phase of the problem; the more direct methods of approach involved the development of a higher resistance to tropical conditions in the equipment itself.

Among these latter methods of approach which were advocated in the reports cited above were the following: Substitution and addition of parts and/or materials, redesign of equipment, and such remedial measures as improved storage conditions, hermetic sealing when possible, the use of dessicants or other means of drying, the use of volatile fungicides, and the application of protective varnishes or lacquers to serve as a barrier against moisture. These remedies were brought to the attention of personnel in the field by means of technical bulletins of the Army and Navy,[6,7] in order to clarify the problems and to serve as a guide in maintenance and repair work.

Of all of these remedial measures, the use of protective varnishes and lacquers was perhaps the most significant and was given the greatest emphasis. This method of approach provided a ready means whereby equipment which was then in the field could be tropicproofed and thereby have its service life extended. This method consisted of applying the protective lacquer or varnish by spraying, dipping, or brushing to the surfaces of finished assemblies or components after masking of parts over which such a coating would be undesirable, such as electric controls, relays, bearings, open switches, etc. As a protection against fungi, suitable toxic agents (fungicides) were added to the coating material. Such treatments were required in all Signal Corps equipment, and they were used extensively by other branches of the Armed Forces as well.

The use of protective coatings was recognized as only a temporary expedient; in practice, retreatments were usually necessary after periods of about six

months. More lasting improvement was possible by change of design and the use of materials which were less susceptible to the effects of moisture and fungus. Detailed considerations were given concerning the choice of resistant materials in some of the reports cited above[1,2,6] and others. Likely directions for improved design were also given.[8,9]

7.3 NEED FOR FUNDAMENTAL INFORMATION

As information accumulated from field reports and from the investigations conducted by Army and Navy laboratories, it was apparent that certain fundamental st[illegible]es would be necessary before the protection of electric and electronic equipment could be improved beyond that given by practices which were then standard. Many questions and problems had arisen which could only be answered by these studies.

Much of the evidence from the field indicated that many failures in performance were due primarily to moisture effects as a result of high humidities and this tended to obscure the precise role which fungus held in the deterioration of such equipment under service conditions. On this basis some investigators felt that the incorporation of a fungicide in any protective lacquer or varnish was unnecessary. Furthermore, the question of the necessary and effective concentration of an included fungicide in a protective coating and the advantage of one or another of the various fungicides available for this use were much discussed, not only with reference to their fungicidal effectiveness, but with reference to toxicity effects on personnel as well. It was argued that for certain applications, lacquer possessed advantages over varnishes because of their shorter drying time, but practically all reports which discuss this point indicate that high-grade varnishes (phenolic resin tung oil type) have a higher water resistance.

7.4 FUNGUS GROWTH ON HOOKUP WIRE

In requesting Project AN-14.1, "Fungus Growth on Hookup Wire," the Signal Corps Standards Agency desired to obtain evidence which would settle these points of conflict. Not only was it desired to determine whether fungus will grow on hookup wire but also to ascertain whether or not there is a deleterious effect. If either braided or unbraided types of wire supported the growth of fungus it was requested that the percentage and types of fungicides required to prevent the fungus growth be determined. It was also requested that investigations be made to determine the effect on the electrical properties of the wire of the leaching of the fungicides incorporated in the lacquers applied to the wire braid or insulation.

A contract for these studies was arranged with the Rensselaer Polytechnic Institute. The immediate objectives of the program as given in OSRD Report 5692[10] were as follows.

1. The first phase was confined to a study of the role of fungus and moisture in the deterioration of wire without respect to the role of fungicides in affecting electrical properties.

2. End tests were also to be made to determine the effect of moisture and fungus on the wear resistance of the various braided coverings used on the experimental wires.

This investigation was begun in the summer of 1945 and by the end of World War II only certain aspects were completed. Preliminary investigations determined the methods of electrical measurements to be used as well as the methods of fungus inoculation. The conditions under which the tests were to be conducted and the methods of determining the wear resistance of test wires were also developed.

7.4.1 Experimental Results and General Conclusions

Preliminary experiments to determine suitable lengths of test wires and desirable spacing of electrodes yielded information on the creepage resistance of different wires under continued exposure at 100 per cent relative humidity and in the presence of fungus growth. After exposure for twelve days the test wires were exposed to the room and allowed to dry for three hours after which the resistance was again measured. The wires used were the following types: SRIR with no braid, a type with polyvinyl chloride primary insulation having cotton braid and acetoproprionate lacquer finish, and a type with polyvinyl chloride primary insulation with an extruded Nylon jacket.

The results of this experiment are given in Figure 1. It can be seen that the behavior of each type of wire follows the same general pattern. A sharp drop in resistance occurred over the first 24 hours after which the values remained relatively constant. When allowed to dry for three hours, after twelve days' exposure in the test chambers, recovery was rapid. To accurately follow the course of recovery necessitates

measurements immediately and at frequent intervals during the drying period.

In addition to the results indicating the general behavior of the test wires, interesting observations on the test equipment and test methods were made as follows.

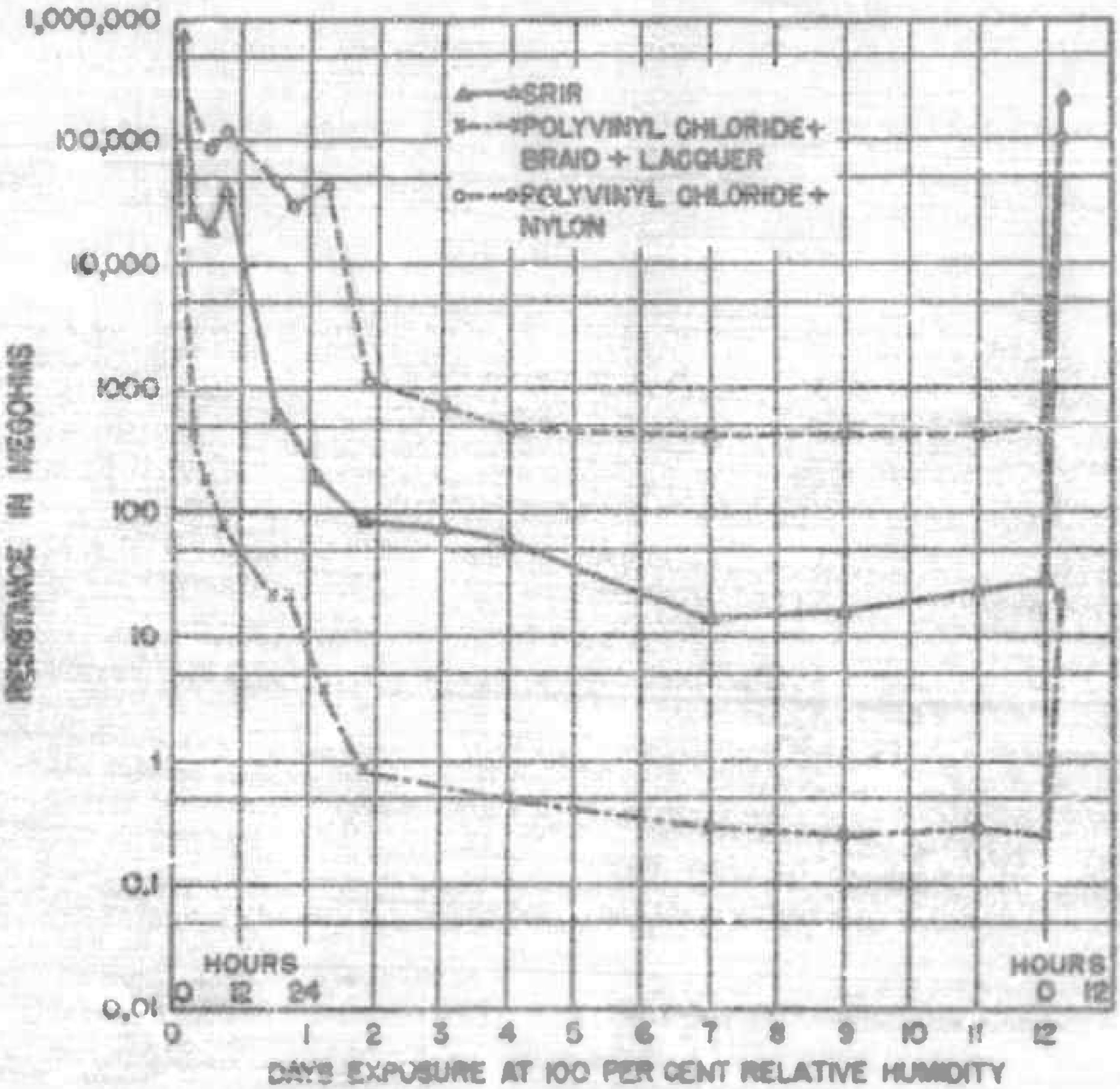

FIGURE 1. Creepage resistance between wrapped electrodes spaced 2 in. apart on 6-in. length of wire.

1. In the attempt to determine whether a 2-, 3-, or 4-in. distance between electrodes was most desirable, it was found that, since the variation in the resistance between apparently identical samples differed by as much as 100 per cent, no valid conclusions could be drawn since only two samples of each wire type were used.

2. However, there were indications that wires having the electrodes 2 in. from the ends showed a more rapid reduction in resistance which indicated that the resistance path over the ends was significant, and therefore the test method should be refined to eliminate this loss.

3. The SRIR wires particularly showed heavy mold growth except for the region about 1 cm on each side of the copper electrode. Evidence was obtained which

indicated that this was due to the fungicidal action of the copper rather than the electric current. Because of this evidence it was decided to use platinum rather than copper electrodes.

4. It was observed that the resistance in some samples would increase by a factor of 5 or 10 if the test voltage were applied for more than a few seconds. Further investigation over a wide range of test voltages will be necessary.

7.4.2 Direction of Future Work

To solve the problem fully, the role of each element of a complete insulated wire should be studied in relation to deterioration under humidity and fungus. The necessary wires for this have been assembled. It is expected that it will be possible to differentiate between the primary insulation, the braid or jacketing, the lacquer or varnish, and the fungicide. The electrical tests should provide this information and the abrasion tests should relate the electric properties to the wear resistance of various wire components. Once the fundamental properties are known from the wires used, it will be possible to investigate the role of fungicides in the lacquers and varnishes. It has been suggested that certain fungicides are incompatible with the coating materials, that they deteriorate the electric properties of the wires, and that they are rapidly lost during storage. When sufficient information is obtained to permit conclusions with respect to these questions, it will be desirable to check the results against chemical analyses.

Despite the fact that it was only possible to begin these studies by the Tropical Deterioration Administrative Committee, the important problems presented are being investigated further under the sponsorship of the Air Technical Service Command.

7.5 EFFECTS OF MOISTURE AND FUNGUS ON ELECTRICAL INSULATING MATERIALS

Investigations on this subject were closely related to those concerning hookup wire. The primary purpose in these studies was to sample a wide selection of laminated and molded thermosetting plastics and rigid thermoplastics in order to obtain information which would indicate the nature of their performance in equipment under tropical conditions. The program which was to be followed called for mechanical as well as electrical tests which were to follow Joint Army-Navy Specifications P-13, P-14, and P-15 as closely as possible. Inasmuch as exploratory work was necessary in the portion of the program involving the electrical determinations, this portion was undertaken first. As with the investigations on hookup wire, these too were begun in the summer of 1945 and at the end of World War II only a satisfactory test method and a few preliminary results had been obtained. However, the majority of materials had been obtained, and by the end of September 1945 most of those on hand had been placed under test. The lack of results from all samples under test is explained by the fact that inordinately long exposures and test periods are required to obtain significant information.

A survey of Army, Navy, and industrial laboratories indicated that extensive systematic studies of the influence of electrical and mechanical properties of plastics had not been made.[11] Most of the work which had been done seemed to have been undertaken to solve specific and immediate problems involving selected plastics and the efficacy of fungicides and protective coatings in preventing fungus growth. Selected available data are presented in the report cited above, and these should be more significant when evaluated in the light of information from these completed studies. The program is being continued by the Air Technical Service Command.

From the data which were received, the deleterious effect of moisture on electrical insulating materials was apparent. Very few of the citations, however, relate fungus effects to moisture effects. Considerable emphasis and importance was attached to the studies of H. L. Curtis, "Insulating Properties of Solid Dielectrics," (Bulletin of the Bureau of Standards, 1915, Vol. 11, pp. 359–420), not only in these studies, but in others performed in Australia with particular reference to insulating varnishes.[12] Foremost among the conclusions of Curtis' work is that surface conduction is the most important factor in determining the leakage between two conductors insulated by a solid dielectric when in an atmosphere of high humidity. However, there is a definite relationship between surface resistivity and the electrical characteristics of the dielectric as indicated by volume resistivity.

7.5.1 Determining Methods of Test

Preliminary investigations indicated that 2-in. diameter disks were suitable for surface-resistance

measurements, and by employing a third electrode, volume-resistance measurements could be made on the same sample. In this three-electrode sample, the disk is mounted in a sealed glass jar with a metal top and all three connections are brought through by steatite bushings. The metal jar top becomes a part of a guard circuit and prevents leakage current (except on the sample) from getting into the measuring circuits. The electrodes on the samples consist of silver paint. Electrode III, 1½-in. diameter, is made in the center of one side of the 2-in. disk and on the opposite side, Electrode I, ½-in. diameter, is placed in the center while Electrode II covers the peripheral ½-in. of the sample. By suitable connection from a megohm bridge, electrostatic lines of force can be directed into the surface or into the volume. Humidity is controlled by saturated salt solutions in the bottom of the jar, and fungus is eliminated from control samples by the use of a nitrogen atmosphere. OSRD Report 5891[12] describes this test method as well as the initial results on test samples.

The specifications to be followed require a different method of measuring the electric properties but the investigations have indicated that the three-electrode sample provides more fundamental information due to the fact that surface and volume effects are separately measured. However, the data from the three-electrode samples is being compared with data from the Pratt-Whitney Pin sample, called for in the specifications, with a view to effecting a correlation.

In all samples which were inoculated for fungus tests, spores of *Penicillium luteum* have been applied by spraying.

7.5.2 Experimental Results

Early results are reported for selected laminated thermosetting materials and the rigid thermoplastic materials polystyrene, cellulose acetate, and acetate butyrate. The latter materials were exposed only to humidity, and after ten days polystyrene was virtually unaffected by humidity, acetate butyrate only slightly affected, while cellulose acetate showed a marked decrease in both surface and volume resistances.

Tests on the laminated thermosetting materials extended over 35 days. All show a great decrease in resistance and particularly a sharp drop in the initial 24 hours. Comparison of data from the three-electrode samples with that from the Pratt-Whitney Pin samples indicates that this decrease is primarily due to a drop in surface resistance. Although tests had not been in effect long enough to evaluate effect of fungus on a wide variety of materials, it is evident that where copious fungus growth is present, the sample is found to be highly moisture absorptive. With fungus-attacked laminates the growth invariably started upon the cut edges.

It is expected that with the separate evaluation of the effects of moisture and fungus upon the surface resistance and volume resistance of various types of plastics, the information will permit a realistic interpretation of the performance of electrical insulation under tropical conditions. The results from test samples can be applied to such finished parts as octal sockets, tube bases, and Jones strips, but it is perhaps more important that they can furnish a working basis for the selection of high quality materials in the design of new equipment for tropical service.

Chapter 8

COORDINATION OF TEST METHODS

8.1 APPLICATION OF TEST METHODS TO STUDIES ON THE PREVENTION OF TROPICAL DETERIORATION

Test methods are necessary and desirable during all phases of study on the prevention of tropical deterioration. The characteristics and properties of fungi and bacteria, the biological agents of deterioration, are determined by various methods designed to indicate the ability of these organisms to thrive upon and thus deteriorate specific materials. In the development of protective treatments for materials, screening tests are employed to determine the merits of protective agents which are promising. Tests for final evaluation of treated materials are considerably more refined than screening tests and include not only biological tests but physical tests, such as exposure to moisture, heat, and sunlight, and others of an electrical or mechanical nature as may be required. In addition, a period of exposure in a tropical area has been used as a final test.

Such tests which are generally referred to above may be described as research and development tests in that they constitute an integral part of any development program. In contrast to these are those tests which have been applied in the procurement of materials, or "specification tests." These are used to determine the fitness of materials for tropical service by their ability to meet standards which are regarded as adequate for indicating satisfactory performance in the tropics.

Research and development tests which have been found to be useful in the development of methods of protection for optical instruments are given in the bibliographic entries of Chapter 3. Electrical test methods are discussed in Chapter 5 and given in greater detail in the references cited. The field exposure tests which have yielded valuable information on the prevention of textile deterioration are reviewed in Chapter 4. There are summarized in Chapter 9 the results of the testing program in which the performance of a wide range of materials was determined by exposing them to natural and simulated tropical environments.

When the work of the Tropical Deterioration Administrative Committee [TDAC] was first started, there was no uniformity or general agreement as to test methods with the result that it was often impossible to duplicate test results in different laboratories. It was, therefore, obviously a prime essential to develop standard conditions for tests which could be agreed upon by all laboratories and thus permit duplication of results on a given sample regardless of the laboratory in which it was tested. It was for this purpose that the Subcommittee on Coordination of Test Methods was established.

This subcommittee prepared OSRD Report 6056,[1] which summarizes and evaluates the test methods which have found wide application in tropical deterioration studies. The introduction to this report considers the primary factors which must be borne in mind in relating any laboratory test method to the particular use or service to be made of the items tested. The criteria upon which a choice of test organisms should be based are also discussed. The discussion on the early development of test methods indicates the various types of methods which have been employed, particularly in textile testing, such as pure-culture tests using different organisms, mixed-culture tests, soil-burial tests, and soil-suspension tests. With such tests as these, evaluation of the performance of tested fabrics is usually made by determining the retention of breaking strength. Initially, such test methods were developed for evaluating protective treatments for textiles, but in a later section, this report indicates the use of natural and simulated tropical conditions, particularly in cases where these more or less refined procedures for textile testing are not applicable. OSRD Report 6056[1] also gives attention to the role of microorganisms in deterioration, methods for testing fungicides, physical conditioning of test samples, the testing of all types of specific Army and Navy materials, as well as a detailed review of various laboratory culture methods, soil-burial methods, and soil-suspension methods.

8.2 TEST-METHOD STUDIES

As stated above, the program on the coordination of test methods was undertaken in order to achieve uniformity in the testing procedures which were used by different laboratories and organizations. For many items or classes of materials, different test methods were in use, or different strains or species of fungi

were used by different groups in applying the same method. Not only was attention given to the coordination of methods which were widely used, but studies essential to the development of certain new test methods were also made.

8.2.1 Hookup Wires

The laboratory investigations in which the variable factors in the testing of hookup wires were studied are summarized in OSRD Report 5686[2] issued by TDAC. In the introduction to this report, the need for protection against fungus growth on hookup wires is briefly stated. Because many different methods were being employed by the various laboratories concerned with the problem of fungus resistance of hookup wires, the Subcommittee on the Coordination of Test Methods was requested to study this problem and to recommend a satisfactory method for an acceptance test for hookup wires.

In order to determine the amount of variation in test methods used at different laboratories, a questionnaire was sent to a number of laboratories which made routine tests on hookup wires. A résumé of the replies to this questionnaire indicates variations in test methods as follows. (1) All the laboratories questioned used a culture medium containing a nutrient, although all of them used an additional test consisting of soil contact, soil suspension, or a nonnutrient medium. (2) The temperature used varied from 25 to 37 C. (3) The durations of the tests varied between five and thirty days. (4) There was considerable variation in the organisms used in the test. Although most of the laboratories used Chaetomium, Aspergillus, and Penicillium, some had added Trichoderma and Actinomycetes, while a number used an unknown mixture. (5) All laboratories depended upon a visual test in expressing results. Several also used tensile strength, abrasion resistance, and electrical tests. This lack of uniformity of testing procedure could certainly be responsible for the expression of entirely different end results. It appeared evident that some standardization of a testing technique was desirable.

In OSRD Report 5686[2] the detailed results are given for exploratory tests on hookup wires using mineral salts agar, nutrient agar, soil contact, soil burial, a moist chamber, and pre-inoculation of filter paper moistened with a liquid culture medium in which fungus spores were suspended. These initial tests indicated that the method in which a mineral salts agar was used would produce more meaningful results in a shorter time and with less difficulty than with any of the other methods. Following these studies, experiments were conducted to determine the most suitable method for culturing fungi to obtain spores for inoculation of test specimens, and methods for inoculation. The test method as finally recommended is given in the Appendix of OSRD Report 5686.[2] In this final method, advantage was taken of suggestions and comments from various Army and Navy laboratories to which a tentative method has been submitted previously. This method was selected because it gave the most reliable and satisfactory results in estimating the fungus resistance of a wire under warm and humid conditions favorable to fungus development. The results obtained by this method checked well with practical observations in tropical chambers as well as under natural tropical conditions.

Significant results, given in OSRD Report 5686,[2] indicate that the recommended acceptance test for hookup wires as an accelerated test procedure compares favorably with long-duration exposure under simulated tropical conditions. On the basis of the method of rating which was adopted in evaluating the performance of test wires, the same wires which were judged to be satisfactory by use of the recommended acceptance test were also satisfactory after an exposure for one year in a tropical house. Likewise, wires which were rated as unsatisfactory by the acceptance test were also rated unsatisfactory after the one-year exposure in the tropical house.

In order to determine the extent to which the recommended acceptance test might give consistent results when used by different investigators, cooperative tests in which five other laboratories participated were arranged. These tests were performed on eleven different treated and untreated types of hookup wires which were furnished to the participating laboratories. One of the participating laboratories was the Tropical Test Station in the Panama Canal Zone. In order to obtain further comparison each laboratory tested the same wire samples according to the test methods required by Signal Corps Specification 71-2202A and the JAN Specification C-76. The general conclusions and comparisons of the results of these cooperative tests are also given in OSRD Report 5686.[2] From the analyses of the data obtained, it is indicated that the acceptance test recommended by TDAC showed greater agreement in results from various laboratories and better correlation with tropical behavior than did the other [illegible] which were used. It was apparent from these analyses that some [illegible]

methods was free from discrepancies as measured in terms of exact correspondence with tropical exposure. It is conceivable that such discrepancies result in part from inexact criteria of rating samples, since borderline cases must be rated in one or the other of two classes with reference to the ability of the specimen to support fungus growth. On the other hand, such discrepancies indicate that further investigation is needed before strict evaluation of the fungus resistance of these materials can be made in terms of actual tropical exposure.

8.2.2 Coating Materials

The laboratory investigations which served as the basis for a recommended acceptance test for coating materials are given, as well as the method itself, in OSRD Report 5687.[3] In this report it is indicated that differences in function between hookup wires and coating materials, such as lacquers and varnishes, make it impractical to use the same method in testing the fungicidal resistance for both classes of these materials. Tests of hookup wires on which lacquers or varnishes may have been applied evaluate the performance of the materials of the wire in combination with any fungicidal or coating treatment which may have been given to the wire, whereas tests of coating materials as such should be made so as to evaluate the fungus resistance of only the lacquer or varnish. The recommended procedure for the testing of hookup wires was followed in the recommended test for coating materials but with modification to provide a suitable inert surface and base which would not influence the performance of the coating material itself.

The major problem in developing this test method for coating materials lay in the selection of the inert base to which the coating material would be applied. For this purpose, tests were conducted in which various coating materials were applied to glass fabrics, filter paper, and glass cords. On the basis of the detailed results which are given in OSRD Report 5687,[3] glass cord was selected for various reasons as the most suitable base on which the coating lacquer or varnish might be applied in the test for fungus resistance. The modification of the test method for hookup wires in which coated glass cord serves as the test specimen is given in Appendix of OSRD Report 5687.[3] Data are also presented in the report which indicate that laboratory results obtained by use of this method compare favorably with the results of the exposure of coated glass-cord samples to the natural conditions of the tropics.

8.2.3 Plastics

The lack of any reference to the tropical deterioration of plastics in the open scientific literature through 1944 is indicated in Chapter 5. This fact, as well as the fact that only meager information has become available since, led to the recognition that a laboratory method suitable as an acceptance test for plastics to be used in the tropics was highly desirable. In their early deliberations the Subcommittee on Synthetic Resins, Plastics, and Plasticizers recommended that such a test be developed, and discussed the problems involved in such a test with the Subcommittee on Coordination of Test Methods. Laboratory investigations basic to such a test method were undertaken and the results of these studies guided the subcommittee in the preparation of a test method for determining the resistance of plastics to fungus attack. These laboratory investigations are summarized in detail and the recommended test method is also given in OSRD Report 5688.[4]

Prior to the initiation of specific studies pertinent to the development of a test method for plastics, it was arranged that a series of plastic samples in which one ingredient was varied at a time be tested at the University of Pennsylvania. These samples were prepared by the Bakelite Corporation in conjunction with studies which they were conducting for TDAC, and for these tests a duplicate set of their experimental plastic formulations was furnished. These original tests served as a background and a point of departure in the investigations related to development of a test method for plastics. The specific formulations of the test sample are given in OSRD report 5688[4] and OSRD Report 5683[5] prepared by the Bakelite Corporation for TDAC.

The detailed results of the exposure of these plastic samples for three months in a tropical house and for 35 days on a mineral salts agar are given in OSRD Report 5688.[4] In general, the results show that incubation on mineral salts agar for 35 days gives rather close correspondence with exposure in the tropical house for three months. The importance of a test period of adequate duration is indicated by the fact that 18 samples which showed slight growth, if any, after incubation on mineral salts agar for 15 days, showed moderate to heavy growth after incubation of 35 days.

In an attempt to determine whether quantitative methods would be more accurate than visual rating in evaluating the significance of fungus attack on plas-

ties, a few selected samples from this experimental series were oven-dried and carefully weighed, and then these were subjected to fungal attack on mineral salts agar for 35 days, after which they were again oven-dried and weighed. Some samples showed as much as a 4 per cent loss in weight, but this weight loss was not correlated with the occurrence of fungus growth. In the report of this experiment it is commented that the criterion of weight loss would not be significant for all plastics in so far as functional aspects of the materials are concerned. Additional test methods, such as a soil-contact method, a soil-suspension method, and use of a nutrient medium with and without pre-inoculation, were tried in testing selected plastics but with all of them the results were considered as unreliable.

Study was also made of various methods of inoculation of test samples of plastics as well as the effect of nutrients added to the spore suspension with which the test samples were inoculated. Further, information was obtained on the comparative fungus development on smooth surfaces versus sanded surfaces and on smooth or molded edges versus cut edges. Slight depressions were also drilled in the smooth surfaces of one set of the samples for this experiment. On only one sample was there any marked difference between growth on cut edges versus growth on molded edges and this same sample was the only one which showed any greater growth on drilled depressions than on molded edges. In only a few instances did the sanded surface develop any greater degree of growth than did the smooth surface. Whenever any great difference occurred between growth on the surface and growth on the edge, the greater growth occurred on the edge. It seems that the most likely explanation for this is the fact that at the junction of the sample and the culture medium one or more physical factors may contribute to produce the most ideal conditions for fungus development. On the basis of these results it would appear to be unnecessary to cut samples or to otherwise expose internal areas, but this factor deserves to be checked further.

The test method recommended for determining the resistance of plastics to fungus attack is given in the Appendix of OSRD Report [illegible].[4] The set of samples identical with those tested by use of the recommended method were exposed at the Panama Test Station for a period of seven months and the results obtained from this tropical exposure of plastics agree rather closely with those obtained by use of the recommended laboratory method. It is interesting that in the tropical exposure test there is more evidence than in the laboratory test that growth on cut or broken edges may exceed that which occurs on unbroken surfaces. A sample of phenolic fiber sheet showed complete overgrowth on all cut surfaces but only partial growth on other surfaces. In the laboratory tests, however, all surfaces were equally affected. OSRD Report 5688[4] points out in conclusion that further attention should be given to evaluation of growth on the edge of a plastic test sample. A refinement or modification of interpretation of this growth is needed to clarify the situation. It is also pointed out that there is a distinct need for functional tests of plastics in order to obtain more precise criteria for evaluating the degree of deterioration which occurs. This report also concludes (as pointed out in Chapter 5) that further correlation is needed between laboratory testing of plastics and field testing in the tropics, and that because of the complex nature of plastics an extensive study of plastics with respect to su[illegible]bility to fungus attack is needed by laboratory test methods as well as field exposure methods under the natural conditions of the tropics.

Biological Factors in Determining Fungus Resistance of Plastics

In addition to the studies conducted by the Bakelite Corporation referred to in Chapter 5, which concerned the ability of different plastic ingredients and formulations to support fungus growth, a study was made of various biological factors influencing the growth of fungi on plastics with the immediate goal of improving the method of testing fungus resistance under laboratory conditions and at the same time adding to the general basic information on the subject. The acceptance test method referred to previously was followed except where certain test procedures were under consideration. Particular attention was given to the various effects of specific methods of inoculation and comparison of the growth of 32 different fungi when applied singly or in various combinations of mixed cultures. The results of these studies are given in detail in OSRD Report 5683[5] and are summarized as follows:

1. A study was made of various biological factors influencing the growth of fungi on plastics. Some 32 different cultures of fungi representing 20 species were used. The fungi were for the most part isolated from material attacked in the tropics and the major sources were the Australian Mycological Panel, the British Ministry of Supply, and the U. S. Department of

Agriculture. Most organisms recommended for inoculation tests by the Australian and British authorities and by TDAC were included.

2. The three representative plastics chosen were the vinyl chloride acetate copolymer Vinylite VU 1900 and Vinylite VU 5904, and the phenol formaldehyde cloth-base laminate Lamicoid 6030.

3. In general the TDAC recommended method of testing was followed except when the various test procedures were under consideration. One-inch squares of the plastics on standard mineral salts agar in petri dishes were inoculated. The extent of growth ranging in five classes from none to very heavy was given numerical ratings of 0, 1, 4, 10, and 20. To date over 3,000 petri dish culture observations have been made.

4. Inoculation by atomization under a hood reduced contamination as compared to inoculation by the drop method, presumably because of greater competition furnished by the widely distributed inoculant spores. The former method is accordingly recommended.

5. The amount of growth is dependent on the concentration of the spore suspension inoculum up to 2,000 spores per sq in. of plastic surface. Furthermore, the growth of contaminants is reduced as the amount of inoculum is increased. Single and mixed culture inoculations should be standardized as regards spore concentration, a minimum of 1,000 per sq in. per fungus is suggested, while 100,000 to 1,000,000 would be preferred for reducing contaminant growth.

6. Since a given fungus culture under standard conditions tends to produce the same quantity of spores, a constant dilution factor may be used in preparing the standard inoculum. The different fungi studied varied in their spore yields per test tube culture from 10,000 to 1,000,000,000.

7. Observations were made at 5, 10, 20, and 40 days after inoculation. Most inoculant fungi reach a peak of growth within this period; a few, however, continue to maintain a high level of growth. Most contaminants reach their peak of development later than the inoculants.

8. Comparisons were made of the growth of the different fungi in single culture on the plastics. The various fungi showed diverse properties, some grow well on all three plastics, some on only one or two, some on none. In general, the greater the growth of inoculant, the less the growth of contaminants. Some fungi reach an early peak of growth and die off; this is more or less typical of the Penicillia. The Aspergilli as a group show more sustained growth. On the basis of relative amount of growth and freedom from contamination the fungi were rated in five classes as to desirability as test organisms in single culture.

9. Contaminating fungi were identified in as far as feasible and their relative abundance noted. For the most part they consisted of the more active genera carried in pure culture. Only one new species, provisionally identified as *Aspergillus fumigatus*, was observed.

10. Several series of mixed cultures were studied. One was composed of TDAC recommended organisms, a second of the British cultures, a third of the remaining fungi, and a fourth of all the cultures. Marked differences were noted; most fungi behaved as in single culture but a few were unable to meet mixed culture competition. The dominant organisms in descending order for the fourth series of all fungi were: VU 1900—Penicillium spp., *Aspergillus flavus*, and *Curvularia lunata;* VU 5904—Penicillium spp.; Lamicoid 6030—*Chaetomium globosum, Memnoniella echinata, Metarrhizium glutinosum*, Penicillium spp., *Curvularia lunata*, and *A. flavus*. Of minor importance on all three plastics was *Rhizopus nigricans, A. ustus*, and especially *A. nigricans*.

11. Further single and mixed culture studies now in progress support the above point to the specific dominance of *Penicillium luteum* 41, *Aspergillus (fumigatus?)* RTI, and *A. flavus* 3.

12. Mixed cultures are recommended for general testing. On the basis of this study to date, the following organisms are considered most desirable for mixed culture inoculations of plastics and plastic components:

Penicillium luteum 41
Aspergillus (fumigatus?) RTI
Chaetomium globosum 1042.4
Memnoniella echinata 2

For a wider selection, the following may also be included:

Penicillium sp. 1336.2
Aspergillus flavus 3
Curvularia lunata 46
Metarrhizium glutinosum 1334.2

8.3.4 Pure Culture Methods for Testing Textiles

Certain of these studies were undertaken as a result of decisions which were made during a Conference on Biological Testing and Test Organisms which was arranged and sponsored by TDAC,* particularly those studies on the effect of the nature and composition of

culture media on textile deterioration by microorganisms and those involving a comparison of strains of *Aspergillus niger* for textile testing. A comparison of cellulose degradation by two species of Chaetomium was also made. The investigations of sterilization treatments in pure culture studies of textile deterioration by microorganisms were the outgrowth of cooperative tests with the American Association of Textile Chemists and Colorists to determine the reproducibility of various textile testing procedures. The results of these studies are given in OSRD Report 5689.[7]

In addition to studies, the nature of which is indicated above, limited experiments were conducted to determine the relation of hyphal penetration of fabric fibers to loss in tensile strength which occurs in fabrics when they are exposed to fungus attack. The observations which were made strongly suggest that fungus deterioration of cloth is not always directly related to the hyphal penetration of fibers. In some instances, particularly in young cultures, it appeared that fibers with breaks in their walls contributed to loss in breaking strength of the cloth in which there was seldom any penetration of the hyphae into the lumina of the fibers. This suggests the possibility that some textile breakdown, following inoculation, may result from a digestion process by enzymes or other secretions of the hyphae in contact with the fiber surface. Studies on this aspect of fabric deterioration which were conducted at the Philadelphia Quartermaster Depot,[4] however, have led to a different interpretation in that they suggest that the period of rapid decline of tensile strength, after the penetration of the fiber wall by the fungus hyphae, corresponds with the period of rapid growth of fungus in the lumina of the fibers, and that enzymatic action on the exterior of the fiber presumably accounts for very little of the total decline of fiber strength. It is obvious from these conflicting interpretations that further information is needed on this point.

In the report of the Conference on Biological Testing and Test Organisms, the discussion which centered around the use of different media in pure culture textile tests is recorded. In practice, presumably standard media as used by different laboratories have been modified slightly to give rise to considerable variations in results and conclusions. A comparison made of the basic media used in various laboratories for pure culture microbiological tests revealed that, for a given incubation period, standard organisms produced varying reductions in breaking strengths of textiles when tested upon the different media, notwithstanding the use of a generally standardized technique. This indicates that, for purposes of standardizing exposure trials of fungicidal treatments, there should be proper selection of the basic agar medium in pure culture tests, inasmuch as pure culture tests are widely used in laboratory trials of fungicidal treatments. The conditions which particularly influence a variation in results are whether or not a carbon source was supplied (maximum vegetative growth with little or no deterioration of cloth usually occurred in the presence of a carbon source), the pH of the medium (somewhat greater losses in breaking strength occurred on the more alkaline substrates), and the nitrogen supply in the nutrient medium.

The Conference on Biological Testing and Test Organisms decided that a comparison of the strains of *Aspergillus niger* for textile testing was desirable, particularly since many different strains of the organism had been used in various types of testing and because evidence was available that at least some of these strains differed in their physiological properties. Certain specifications require materials to pass tests in which *Aspergillus niger* is used but they do not specify a particular strain, and it was visualized that these studies would indicate the desirability of using specific strains and give an indication as to which strains were more suitable for textile testing purposes. In all, fourteen different strains of the organism were acquired for these comparative studies. Investigations of the resistance of the strains to fungicides were made with the fungicides incorporated into fabrics and with the fungicides incorporated into the culture media. The ability of the various strains to decompose cellulose was determined as was their ability to compete with other organisms. The results as recorded in OSRD Report 5689[7] show that the different strains did not vary markedly in their tolerance to fungicides except for two strains which were also less aggressive in competition with contaminating organisms and produced only meager sporulation. This pertains to studies with fungicides incorporated into fabrics. Greater variability was seen among the various strains where fungicides were incorporated directly into the agar and some strains characteristically produced variants under these conditions. In general, one strain exceeded all others in effecting reductions in tensile strength of gray cotton duck in several inoculations [illegible] No strains were particularly aggressive [illegible] with other fungi in cultures and those

strains which were least tolerant to fungicides incorporated in the fabrics showed little or no growth at all under these conditions.

In the studies concerning the ability of species of Chaetomium to degrade fabrics in pure culture tests there were no significant differences among four strains of *C. globosum*, and a strain of *C. elatum* appeared less effective than any of the strains of *C. globosum* in the experiments conducted.

In pure culture tests of fabrics on mineral salts media, aseptic conditions are rigidly maintained during inoculation and incubation procedures. The sterility of the cloth, however, may or may not be ignored. Various undesirable conditions result when contaminating organisms present on the fabrics develop and these may affect the results of the tests. If sterilization of the test cloth is to be followed, the cellulose and other constituents of the fabric should not be altered; the cloth should be as susceptible to the effects of the test organisms before and after treatment; where treated cloth is used, the effect on test fungi must not be changed by sterilization; and any disinfecting agents should be easily removable from the cloth so that the test organisms are not affected.

The tests which were conducted in these investigations employed two methods of sterilization: (1) chemical sterilization through the use of volatile fungicides which were easily removed from the fabric before inoculation and which did not enter into direct chemical combination with any ingredient of the cloth; and (2) physical sterilization such as by steam or dry heat. The experiments described in OSRD Report 5689[7] concern the use of formaldehyde and methyl alcohol as volatile fungicides. So far as chemical sterilization is concerned, it was found that the length of the exposure required to insure complete sterilization was generally prohibitively long to warrant the use of such agents as a means of sterilizing cloth for inoculation tests. Formaldehyde was retained by the cloth for long periods and excessively long aerating times would be required to thoroughly remove the last traces of disinfectant before inoculation tests could be performed without danger of interference with the test organisms. Cloth sterilization with steam under pressure appeared to offer the most satisfactory practice for routine use. Small reductions in tensile strength did occur after autoclaving and in inoculation tests a trend was indicated for fungus deterioration of the cloth to become somewhat reduced with increasing exposure to the steam sterilizing conditions.

8.2.5 Evaluation of Tests Results in Terms of Field Performance

The ideal test method to determine whether or not a particular item of military equipment or material is suitable for tropical service is to expose the item to the natural conditions of the tropics as a final test. It is, however, obviously impossible to do this except perhaps in a few cases, particularly in time of war; consequently, reliance must be placed on accelerated tests which have been shown to correspond to much longer periods of tropical service. In only a very few instances have beginnings toward this goal been possible, even with the increased testing program during World War II, and the necessary investigations to relate these accelerated tests to performance in the tropics still remain to be performed in most instances. The necessity for further studies to standardize and refine the various test methods used in laboratory studies on the prevention of tropical deterioration are indicated for many materials, and maximum benefit of such improved methods can only be derived when they have been adequately correlated with exposure to natural conditions of the tropics.

Chapter 9

RESULTS OF TESTING MATERIALS UNDER TROPICAL CONDITIONS

9.1 LOCATION OF TROPICAL TEST STATION

In the testing program of the Tropical Deterioration Administrative Committee [TDAC], exposure of materials to the natural conditions of the tropics has been made in connection with fundamental studies on the deterioration of fabrics which are discussed in Chapter 4 and in studies on the prevention of tropical deterioration of optical instruments which are discussed in Chapter 3. These exposure tests of optical instruments constituted field trials of the most promising methods for protecting the instruments. Tropical testing was not limited to those studies cited above, however, and the results of tropical exposure tests of a wide variety of other materials are summarized in the following sections.

The tropical exposure testing was performed under natural conditions at Barro Colorado Island, Panama Canal Zone, and under simulated tropical conditions in a specially constructed tropical house in which temperature and humidity could be closely controlled at the University of Pennsylvania. Section 9.2 will deal with the results of exposure tests in Panama, and Section 9.3 discusses the results of the exposure testing in the tropical house at the University of Pennsylvania [UP]. Limited testing using balanced mite-fungus populations was performed at the University of Pittsburgh and Section 9.4 deals with the results of these exposure tests.

The Tropical Test Station was established at Barro Colorado Island situated in Gatun Lake, Panama Canal Zone. This island was set aside as a biological reserve in 1923 and has since been established as the Canal Zone Biological Area by an Act of Congress. The facilities of Barro Colorado Island were made available to TDAC by the Board of Directors of the Canal Zone Biological Area. A description of this testing station is given in OSRD Report [illegible][4] along with information on the rainfall, relative humidity, and the fauna and flora, particularly fungi, of the region. The report describes the laboratory facilities which were available and the nature of the exposure facilities. There were established a sun-exposure site, a shade-exposure site, an open jungle shed, a closed storage shed, and a jungle-exposure pen; the contrasting conditions which these different sites offer are presented in this report.

The Tropical Test Station was established by UP in conjunction with their studies on the prevention of deterioration of optical instruments, but it was soon realized that by the use of these facilities for the exposure of other materials, valuable information could be obtained. Accordingly, invitations were extended to offices of the Army and Navy to submit material for exposure at the station. All arrangements were made through TDAC, and the results of the exposures were in turn made available to the submitting offices by the committee. The summaries of results which are given below have not been previously reported, except in a few instances. In all, a total of over 15,000 individual items were exposed in Panama.

9.2 RESULTS OF EXPOSURE TESTS IN PANAMA

In the following discussion of tests, those items such as textiles or packaged materials which were sent to the station for exposure and return to the submitter are not indicated.

Flying Clothing Material

These materials were submitted by the Aero-Medical Laboratory of the Air Technical Service Command and included fourteen different samples of various types of fabrics and leather materials. These were exposed in a roofed jungle-exposure chamber for a period of eight months. At the end of the exposure period samples of Nylon, waterproofed boat cloth, and alpaca wool pile were generally in the best condition and showed little or no fungus growth. Samples of sheep shearling, collar fur, and cowhide showed considerable fungus development on both the leather and fur surfaces. The rayon and cotton fabrics all showed fungus development in varying degrees. None of these materials were given fungicidal treatment.

COATED AIRPLANE FABRICS

These materials were submitted by the National Bureau of Standards in conjunction with work for the Bureau of Aeronautics, Navy Department, and consisted of 1,768 samples which were to be exposed above ground in sunlight, above ground in shade, on the surface of the soil, and buried in the soil. Three sets of eight strips each of seventeen different mildew-proofing treatments were supplied for each exposure condition, in addition to one set to be used for initial breaking-strength determinations. Evaluations consisted of breaking-strength measurements supplemented by visual observations. The results of this study were summarized informally for the Subcommittee on Synthetic Resins, Plastics, and Plasticizers.[3] The test fabrics were coated with four coats of clear cellulose acetate butyrate airplane dope and two coats of camouflage white pigmented airplane dope in accordance with specifications pertaining to coated airplane fabrics. Six different fungicides were applied in two concentrations by incorporating them in the first coat of doping, the other five fungicides were applied to the fabric by the fungicide manufacturer prior to the application of the doping. Only slight changes in tensile strength were noted in the samples exposed in air in the shade. On the other hand, marked losses in tensile strength occurred in the samples exposed in the air in sunlight. Part of this loss is to be ascribed to deterioration of the highly pigmented camouflage white dope and concommitant loss of its light-screening properties. The largest loss occurred in the two samples in which copper naphthenate had been incorporated into the first coat of dope. Relatively large loss in tensile strength was shown by the samples treated with phenyl mercuric salicylate. The smallest loss in sun exposure was shown by the zinc dimethyldithiocarbamate sample with the higher concentration of the fungicide.

Of the samples exposed on the soil surface, those treated with phenyl mercuric salicylate showed good retention of strength. Only a slight change in strength was noted for the control samples containing no fungicide but those treated with dihydroxydichlorodiphenylmethane showed a marked tensile-strength loss. Fabrics treated with phenyl mercuric salicylate, the Harodite process, and zinc dimethyldithiocarbamate showed the best strength retention.

Examination of the fabrics returned from Panama showed that no fungicidal treatment altered the adhesion between dope and fabric except those samples treated with copper naphthenate and exposed to sun and soil burial and those treated with zinc naphthenate exposed to soil burial. On the basis of these results, recommendations were made to the Bureau of Aeronautics that zinc dimethyldithiocarbamate be used as the mildew-proofing compound for coated airplane fabrics.

PACKAGED FRUIT BARS

In addition to the 890 individual bars which were sent to Panama for exposure tests, the same number was sent to the University of Pittsburgh and UP for exposure under artificial tropical conditions. The results summarized here are taken from data from all the exposures.

The samples were submitted by the Packaging Section, Military Planning Division, Office of the Quartermaster General, and they consisted of 2-oz fruit bars double wrapped in various combinations of regular untreated cellophane and cellophane which had been given a special carbon-silver coating, with and without pasteurization after the first wrapping. The carbon-silver coating had been shown to have fungicidal value in preliminary tests and the object of these exposures was to determine its value in protecting such a highly susceptible material as a fruit bar from microbiological attack.

The observations which were made included visual observations on the extent of mold development, and the occurrence of swelling and bleeding at the seams, in addition to weight determinations which indicated the amount of moisture transmitted through the wrappings. Conclusions with reference to the value of the fungicidal coating are as follows:

1. The carbon-silver coated cellophane offered no appreciably better resistance to fungi than did the regular cellophane.

2. The moisture-vapor resistance of the cellophane was lowered in coating it with the carbon-silver mixture.

3. Pasteurization degraded the moisture-vapor resistance of the regular cellophane to a greater degree than that of the coated cellophane. Some evidence was obtained which indicated that the heat of pasteurization effected a more efficient seal of the inner wrapper.

4. The best combination of wrappings, therefore, consisted of an inner wrapping with the coated cellophane, followed by pasteurization before the outer wrap of regular cellophane was applied.

Cases of Shoes with and without Volatile Fungicides

Four cases of shoes, two with fungicidal pellets and two without such pellets, were submitted by the Footwear and Leather Section, Military Planning Division, Office of the Quartermaster General. The volatile fungicide contained in the pellets was trichlorophenol. Two of the boxes, one with and one without fungicide, were opened by error upon arrival at the exposure station. After three months' exposure in a roofed chamber, no mold was evident on the shoes in any of the boxes. Exposure was continued for three additional months in an open jungle pen with the boxes elevated for protection against termites. At the end of this additional three-month exposure, the two cartons with and without fungicide which were unopened did not show any development of fungus on the shoes. However, in the two cartons which had been opened by error, all of the 24 pairs of shoes in each carton showed at least some fungus growth on the stitching in addition to fungus in varying amounts on the leather itself.

Stitched Leather Samples

Each sample consisted of two small pieces of heavy leather stitched together along one edge. Ten different thread treatments, including an untreated control, were represented by six repetitions of each treatment. These were submitted by the Footwear and Leather Section, Military Planning Division, Office of the Quartermaster General.

After 8 weeks' exposure in an open jungle chamber, where they would be exposed to maximum wetting and drying, the samples were broken on a Scott Break Tester. At the end of this period slight visible fungus growth appeared on all the samples, except one set containing Nylon thread. The fungi seemed to be mostly species of Penicillium and the growth did not extend appreciably into the leather.

The breaking strengths for one-half of the different treatments were greater than the capacity of the machine, and these were returned to the submitting office. All of the fungicidally treated samples of thread showed a greater average breaking strength than the untreated control. Those treatments which were only slightly stronger than the control employed Rohm and Haas fungicide R-3258 and a special treatment with copper naphthenate. In addition to the Nylon thread sample, the other treatments which were markedly stronger than the untreated control were tetrabrom orthocresol, phenyl mercury triethanol ammonium lactate, a copper naphthenate treatment, M. fungicide (Arkansas Company), dihydroxydichlorodiphenylmethane, and Hyamine (Rohm and Haas Co.).

Treated Filter Papers

These materials were submitted by the Office of the Chief of Ordnance, in cooperation with the TDAC Subcommittee on Electrical and Electronic Equipment, and consisted of 30 samples of filter paper in five sets as follows: one set—untreated paper, one set—paper dip-coated with paraphenylphenol, tung oil varnish; two sets with one of the following fungicides included in the coating varnish of each—pentachlorophenol and salicylanilide; and, one set dip-coated with Insl-X 25A. The specimens were exposed for a period of approximately seven months, and although the untreated samples showed slight fungus growth after one month's exposure, this disappeared and at the end of the exposure period all samples were free of fungus growth.

Sheet Insulating Materials

The Office of the Chief of Ordnance and the Subcommittee on Electrical and Electronic Equipment submitted these materials jointly. They consisted of 120 samples of three types of phenolic plastic sheet insulating materials. These were separated into twelve sets, four sets of each type of material. Initially one set of each was exposed in a shady and sheltered location, and one set of each was placed in a sunny location. After eight weeks the original exposure was terminated and the entire exposure was duplicated with the remaining samples.

The objective of the test was to determine the extent of moisture uptake by each type of material under the contrasting conditions, and in these determinations weighings on each individual sample were made at regular and frequent intervals. The extent to which the samples absorbed moisture was then compared with the water absorption of these same materials at known humidities and at a temperature of 23 C. The average water absorption by the Panama samples was generally comparable to the performance of the material under laboratory relative humidities of approximately 92 to 95 per cent. Generally the shade-exposure samples showed about a 0.3 per cent increase in weight over the sun-exposure samples.

Plastic Terminal Strips

These samples consisted of five sets of ten samples each of Jones terminal strips. One set was untreated, one was treated with No. 74 Bakelite varnish alone, and the remaining three sets were treated with the above varnish which contained separate fungicides as follows: 1 per cent phenyl mercury salicylate, 5 per cent pentachlorophenol, and 5 per cent salicylanilide. This was a joint project of the Office of the Chief of Ordnance and the TDAC Subcommittee on Electrical and Electronic Equipment.

Frequent resistance readings with a megohm bridge were made at specified intervals for about 3½ months. The exposure was made in an enclosed jungle-exposure chamber where the resistance measurements were made.

An interim report on this test[8] summarizes the results. No fungus growth appeared on any of the specimens. The results indicate that a coating of varnish on such materials as these slows the rate of deterioration by factors of 5 to 10. They further indicate that in these tests the pure varnishes proved to be slightly superior to those containing the fungicides.

Gas Masks

These items were exposed for the Canadian Air Force, and they included masks with three different types of face-piece lining—chamois, fabric, and unlined. During the eight months' exposure of these items considerable mold developed on practically all parts. There were no appreciable differences in the degree to which the different types of face-piece linings supported mold growth. No fungicidal treatment was given to the samples.

Cotton Fabrics

These fabrics also were exposed for the Canadian Air Force; four treated fabrics and one untreated control were included. The duration of exposure in the open jungle was three months. Breaking strength values at one month showed no significant changes. The greatest change after three months' exposure occurred in the untreated sample which lost approximately 17 per cent of its original strength. This untreated sample also showed the highest evidence of fungus growth. The best protection of the fungicides used was given by 1.4 per cent Puratize N5-X (phenyl mercury triethanol ammonium lactate).

Paper Message Pads

These were exposed for the Canadian Army Staff at the request of the Office of the Chief Signal Officer. Exposure consisted of storage for eight months on open shelves in the closed jungle-exposure chamber for some, and a more severe exposure in an open jungle pen for others. Some termite damage was noted in the pads on the bottom of the pile in the closed chamber. The only fungus development occurred to a slight extent on the binding and backing of pads in the open pen, and to a greater extent on dead insects between pages. Generally, those in the closed chamber were in excellent condition, while those in the open jungle pen became badly discolored with yellow, red, and green stains which extended throughout the pads.

Bridged and Steel Panels of Strippable Coatings

These samples consisted of a series of nine panels submitted by the Naval Ordnance Laboratory, Silver Spring, Maryland. Fungicides were incorporated in the materials before spraying but the compounds used were not disclosed. After six months' exposure in the roofed jungle chamber, slight fungus growth was present on about one-half of the panels and in almost all cases it was associated with insect debris. In a few cases the fungus growth had extended out from the insect debris in a smaller circular area ¼ to ½ in. in diameter. No prominent deterioration of the coatings was noted.

Ear Wardens

This series of materials was exposed for the Psycho-Acoustic Laboratory, Harvard University. The ear wardens were made of Vinylite which contained a high percentage of castor oil used as an ingredient of the plasticizer. Five per cent dihydroxydichlorodiphenylmethane was added to some of the samples while others were untreated. These were exposed under varying conditions—indoors and outdoors and inside and outside a small carrying capsule.

After six months' exposure fungus growth was prevalent on the wardens throughout the series. Generally it was more prevalent on the treated than the untreated samples. Invariably the fungus on the treated samples was closely appressed in an oily film which was exuded. This film did not appear on the untreated samples. The exuded oil film probably represented excess plasticizer; therefore, in addition to being

ineffective in the prevention of mold growth, the added fungicide promoted the exudation of plasticizer.

A bluish coloration was noted in both treated and untreated ear wardens and this was attributed to a dye which was transferred from the carrying capsule to the wardens. This had previously been observed in the submitting laboratory and measures were taken to correct this by use of a pigment instead of a dye.

Pouchette Containers for Ear Wardens

These were also submitted by the Psycho-Acoustic Laboratory and were exposed in the roofed jungle chamber. The pouchettes were made of a coated fabric with stitching along the edges and with brass snaps. No corrosion of the metal occurred in the 3½ months' exposure. Surface mold appeared on the exteriors of all samples and within the last month mycelial growth appeared on the interiors of the specimens. More surface growth was present on the stitching than on the plastic coating. At 2½ months, the fabric began to lose its pliability, and at 3½ months this was more pronounced.

Neoprene Earphone Sockets

These items were also submitted by the Psycho-Acoustic Laboratory. The sockets were of two types—sponge neoprene with the sponge exposed, and the same type with a thin sheet of mechanical neoprene over the sponge. Exposure consisted of a three-month period in the roofed jungle chamber. In this period the sockets with exposed sponge picked up about 5 g of water while those with the covered sponge gained only about 2 g of water. This would indicate that the covered sponge type would probably perform much more satisfactorily under prolonged exposure to humidity than the uncovered type, particularly since excessive water absorption would result in marked distortion of the socket.

Test Samples of Strippable Spray Coatings

The Naval Ordnance Laboratory, Silver Spring, Maryland, submitted this series of eight test samples to determine whether they are susceptible to attack by insects or other animals. They were placed in the open jungle and after six months' exposure there was no evidence of attack by any form of animal life.

Glue- and Resin-Bonded Cork Samples

Specimens of both glue-bonded and resin-bonded cork were treated with amyl acetate containing varying percentages of paranitrophenol by the University of Pennsylvania and for each percentage treatment of each type of cork there were leached and unleached duplicates. Studies on optical instruments (Chapter 3) indicated the necessity for fungicidal treatment of cork in such equipment and in preliminary trials paranitrophenol proved to furnish excellent protection. In all fifty samples were included; these were exposed for six months in the roofed jungle-exposure chamber.

Except in the case of the leached resin-bonded cork, no fungus growth appeared on any of the samples which had 1.2 per cent or more fungicide by weight. No significant differences were noted between the glue-bonded and resin-bonded corks. These results are reported in OSRD Report 5684.[4]

Glass Cord Coated with Fungicidal Lacquers and Varnishes

These materials consisting of fifteen 1-yd samples were prepared for exposure by UP in order to obtain information on the performance under natural tropical conditions which could be correlated with laboratory testing procedures in the development of a standard test method for coating materials. The results are discussed in OSRD Report 5687.[5]

Plastic Samples

These materials were also exposed in conjunction with the UP studies on test methods in order to correlate results of tropical exposure with laboratory tests in the development of a standard test method for evaluating the fungicidal resistance of plastics. The results of these studies are discussed in OSRD Report 5688.[6]

Hookup Wires

These included fungicidally treated and untreated wires identical with the specimens used in comparative laboratory trials of different test methods for evaluating the fungicidal resistance of hookup wire. OSRD Report 5686[7] gives the results of these comparative laboratory tests and contrasts these with the results of tropical exposure.

The Office of Research and Inventions, Navy Department, has continued to operate the Panama Test Station through a contract with the UP since the activities of TDAC were terminated. Among the materials which were under exposure when the Office of

Research and Inventions assumed the contract were the following: a set of 8,640 treated cotton fabrics submitted by the Engineer Board, Fort Belvoir, Virginia; a set of 265 samples of treated twines, netting, gaskets, etc., submitted by the Bureau of Ships; and a set of 2,016 fungicidally treated wires, supported in trays, submitted by the Naval Research Laboratory.

Only preliminary reports on these materials had been made prior to transfer of the Panama test station, but it has been the policy of the Office of Research and Inventions to continue exposure of Army materials, as well as Navy materials, and to make the results available to the submitting offices or laboratories.

9.3 RESULTS OF MATERIALS TESTING BY EXPOSURE IN THE TROPICAL HOUSE AT THE UNIVERSITY OF PENNSYLVANIA

In connection with the studies on optical instruments at UP there was constructed a tropical house in which the natural conditions of the Canal Zone were duplicated. Temperature and humidity were controlled so as to provide a daily cycle in which condensation, so important in tropical exposure, would occur on test materials. Representative fungi and insects native to the Canal Zone were introduced to provide biological agents of deterioration. OSRD Report 4048[9] describes the construction and operation of the tropical house.

The tropical house was built while the studies on optical instruments were under the direction of NDRC Section 16.1. After these studies were transferred to TDAC and a broad program of tropical testing was undertaken, this facility was used to supplement tests under natural conditions in Panama. The results of the various tests are summarized in the following. A total of over 1,900 individual items were exposed in the tropical house.

Leather and Fabric Carrying Case

This was exposed for a period of two months for the Engineer Board. The fabric (canvas) was treated according to specifications with copper naphthenate (solvent method) and the leather was dipped in a 1 per cent solution of equal parts of paranitrophenol and parachlorophenol. The leather was extensively molded at the conclusion of the test. Mold was also present on the external fabric but not conspicuously, while the internal fabric surface was irregularly spotted with fungi.

Glue-Cork and Packaged Cork Samples

These materials were also exposed for the Engineer Board and they included 56 samples of glue-cork compositions with various fungicidal treatments and 24 samples of fungicidally treated cork packaged with different materials. The exposure period was two months.

All of the glue-cork compositions had approximately 75 per cent or more of their surfaces covered with fungi. The fungicides used were phenyl mercury derivatives which were applied in varying concentrations and with different solvents.

The same fungicidal treatments were used on the cork which was packaged. Some methods of packaging were more susceptible to fungus attack than others, but a considerable number of samples supported abundant fungus growth—in some cases the packages became unsealed or the labels were obscured. A paraffined package and a metal-foil package which were opened showed the cork contents in excellent condition. All other samples were returned to the Engineer Board for examination.

Ear Wardens

These materials are the same as those exposed in Panama and which are discussed in Section 9.2. In petri dish tests wardens treated with 1, 2, and 3 per cent of tetrabrom orthocresol and dihydroxydichlorodiphenylmethane all supported fungus growth. After one month in the tropical house all remained free from fungus except 1 and 2 per cent treatments of dihydroxydichlorodiphenylmethane, which showed fungus growth near the area of contact with a shelf.

Later, samples with 5 per cent of the fungicides were also tested in culture dishes on mineral salts agar and in the tropical house. All samples in the petri dish tests developed fungus growth in varying degrees. Those in the tropical house remained free from fungi after six weeks' exposure. None of the discoloration or exudation of plasticizer which developed in the Panama exposure occurred with those in the tropical house.

Plastic Samples

This series of materials was prepared by the Bakelite Corporation in their studies on plastics for TDAC

and the ingredients were varied one at a time. Vinylite was the basic plastic present in all the samples. The detailed results with reference to the extent which these materials supported fungus growth after three months' exposure in the tropical house are given in OSRD Report 5688.[6] The results of the tests conducted by the Bakelite Corporation on the same series of samples are given in OSRD Report 5683.[6]

LEATHER FROM JAPANESE SHOE

This sample was taken from an unused shoe in storage. After six weeks' exposure abundant fungus growth was present on the stitching, and could be detected microscopically on extensive areas of the leather. However, macroscopically the leather appeared in relatively good condition. Chemical analysis by the National Bureau of Standards did not reveal any fungicidal treatment. It was further indicated that the leather contained but little grease and that a catechol tanning material was used, therefore little nutrient was available to support fungus growth.

POLAROID LENSES

The Bureau of Medicine and Surgery, Navy Department, submitted these lenses, which were exposed for six weeks. The polarizing lenses were of laminated cellulose acetate composition. Fungus growth associated with organic detritus occurred on the lens surfaces without damage to the lenses. When the lenses were placed on the floor of the tropical house, considerable separation of the laminations occurred with fungus abundant on the inner surfaces of the laminations. Such a test as this is, of course, much more severe than the conditions which the lenses would be expected to meet in use, and it would normally be expected that no fungus damage or separation of elements would occur.

SEAT CUSHION ASSEMBLY

This item was submitted by the Office of the Chief of Ordnance; no fungicidal treatments were applied to any portion of the assembly. The more obvious developments after eight weeks' exposure were the extensive warping of the plywood bottom, pronounced rusting of tacks, and heavy mold over rather large areas of the leather covering. Stitching threads also supported heavy mold growth.

COATED LENSES

These consisted of 40 lenses which were coated with clear lacquers as follows: ethyl cellulose plus 5 per cent Cresatin, ethyl cellulose plus 1 per cent Merthiolate, Vinylite lacquer S-986, Dulac lacquer 86A. These were prepared in conjunction with the program of the TDAC Subcommittee on Optical Instruments. After two weeks' exposure with the lenses supported on glass rods so as to avoid contact with organic materials, the Merthiolate-treated lenses and about half of the lenses coated with Dulac lacquer were free from fungus growth. Practically all of the remainder showed fungus growth in varying degree. During an additional two weeks' exposure organic material was allowed to come in contact with the lenses and four of the ten formerly fungus-free Merthiolate-treated samples developed fungus growth. None of the other treated lenses were free from mold, and all those Cresatin-treated showed heavy growth. Those coated with Vinylite lacquer developed considerable blistering and cracking in the coating.

Another series of lenses coated with similar materials (ethyl cellulose, Vinylite, VYHH, and cellulose acetate, each with 1 per cent Merthiolate (free acid), and Dow-Corning Resin No. 2012 in a surface lacquer) gave similar results after six weeks' exposure. They all supported fungus growth to a slightly greater extent, but the samples were in contact with decaying organic material throughout the period of test. Although the Vinylite-coated samples showed the greatest development of fungi, there were no moisture effects of the coating as in the other coatings.

VELLUMOID GASKETS

These were also prepared in conjunction with the program of the TDAC Subcommittee on Optical Instruments. They consisted of ten samples, some of which were untreated, some soaked in alcoholic Merthiolate (free acid) solution only, and some coated with ethyl cellulose plus Merthiolate (free acid) after soaking. After five weeks those which were untreated showed extensive mold development, but all of the treated samples were free from mold.

COATED PROJECTION SCREEN SAMPLES

These were submitted by the Pictorial Engineering Research Laboratory, Signal Corps Photographic Center, and consisted of samples of commercially available projection screen materials. These samples were inoculated with a spore suspension before placement in the tropical house. After two weeks abundant to heavy growth was present on all of the samples, with slight to severe stains apparent on the white surfaces.

A subsequent set of samples of other screen materials, some of which had fungicides incorporated in the coating, were exposed for 28 days. Fungus growth generally did not develop to as great an extent, nor was staining as widespread. Breaking-strength determinations did not reveal a significant loss of fabric strength in the short period of exposure. The samples were returned to the submitting laboratory for whiteness and brightness tests, but information concerning the results of these tests was not received.

Treated Leather Cases

Three leather cases with different fungicidal treatments were submitted by the Pictorial Engineering Research Laboratory, Signal Corps Photographic Center. Two of them were given the treatment indicated in Ordnance Department Specification AXS-1416. This calls for a mixture of salicylanilide, isopropyl alcohol, wax, and dry-cleaning solvent in specific proportions. With one case the wax was omitted. The other case was dipped in a 1 per cent solution of Santobrite. After 21 days' exposure the salicylanilide-treated cases showed only very slight growth of fungus, while the other showed abundant fungus spotting.

Felt Samples

This miscellaneous lot of different kinds of felt was also submitted by the Pictorial Engineering Research Laboratory, Signal Corps Photographic Center. Fungicidal treatments applied to some of the samples were effective, whereas untreated controls developed considerable mold.

In addition to the materials which are individually enumerated above, other items were tested such as a fungicidal paint, glass coated with a fungicidal lacquer, and a fungicidal lens cleaning compound, but none of these showed any fungicidal properties in the tropical house test.

9.4 TESTS UNDER SIMULATED TROPICAL CONDITIONS EMPLOYING MITE-FUNGUS POPULATIONS

This test method, which has been used at the University of Pittsburgh in evaluating performance of materials under tropical conditions, has been described in OSRD Report 5010.[10] It has been indicated in Chapter 3 that this method was used in the preliminary screening of contact fungicides for optical instruments. The reference report gives the statistical basis for the evaluation of these materials. The studies on optical instruments were begun by NDRC Section 16.1 and were later transferred to TDAC.

The test chambers used in this method are prepared by placing sterile sphagnum moss in the bottoms of containers and then inoculating them with mites and fungi. High humidities are maintained in these chambers. Test materials are placed on the bed of sphagnum, and observations are made at appropriate intervals.

This test method was developed in order to furnish a realistic test procedure for optical instruments in which the mite factor was dominant. In the early investigations on optical instruments as well as on other materials, considerable attention was directed to the role of mites in the deterioration process, particularly as agents by which fungus spores are distributed. Subsequent reports of field observations are not consistent with respect to the importance of mites in the infestation of materials, and the results obtained by this method must be interpreted accordingly.

The following were among the materials tested at the University of Pittsburgh.

Experimental Binoculars Treated with Fungicidal Carbon-Silver Coating

This carbon-silver coating was the same which was applied to the cellophane wrappers of the packaged fruit bars (see Section 9.2). Three pairs of binoculars with cases were used; different formulations of the coating were applied to the interiors of the cases and the interiors and exteriors of the instruments. The duration of the exposure was four weeks.

Fungus growth was particularly abundant on the interiors of the cases, which indicates that the treatment was ineffective in the protection of the leather. Fungus growth was also present in varying degrees in the interiors of the instruments. However, this is explained in part by the fact that the instruments were not sealed and the mites in the test chambers would have had easy access to the interior of the instruments and would thus infect them with fungus spores. This serves to emphasize the importance of sealing optical instruments.

Comparatively little fungus growth was found on the treated exteriors of the binoculars and this would suggest that the carbon-silver coating may have some value in protecting the external surfaces of optical instruments.

Neoprene-Coated Fiberglas Cloth

Three different samples of these materials were placed in the test chambers for a four-week period and the results indicated that these materials did not support fungus growth. These results confirmed tests which had previously been made on similar materials.

Experimental Clutch Facings

These samples were prepared using various percentages of iron in iron-bronze powder mixes, and the principal observation to be made was the extent to which corrosion occurred. The materials were submitted by the Office of the Chief of Ordnance. The detailed formulations were not submitted. Upon return of the materials to the submitter, dynamometer tests were to be made to determine the extent to which real damage resulted from the exposure.

One specific formulation proved to be less susceptible to corrosion than did the other formulations.

Chapter 10

RECOMMENDATIONS FOR FUTURE WORK

10.1 INTRODUCTION

WHEREAS THE FOREGOING chapters of this report have reviewed the problems of the tropical deterioration of equipment and materials and the results of studies to develop methods to prevent such deterioration, this chapter outlines the problems which are still in need of further investigation for the following materials: textiles and cordage, electric and electronic equipment, synthetic resins, plastics, and plasticizers, and photographic equipment and supplies. The aspects of the prevention of tropical deterioration of optical instruments and the coordination of test methods on which further information is needed are given in Chapters 3 and 8 respectively.

At the termination of the activities of the Tropical Deterioration Administrative Committee, the individual subcommittees submitted recommendations which were concerned with problems for future investigation. The recommendations as given here are those which were made by the several subcommittees.

10.2 RECOMMENDATIONS OF THE SUBCOMMITTEE ON TEXTILES AND CORDAGE

1. The effect of light on the decomposition of cellulose should be undertaken as a fundamental study to provide data for use in formulating applications to prevent light deterioration as well as biological deterioration.

2. Research directed toward a modification of the chemical structure of cellulose to increase its resistance to microbiological attack should be encouraged.

3. The use of synthetic fibers, such as Nylon and Vinyon, which are inherently resistant to microbiological deterioration, should be encouraged wherever possible in military equipment which might be used in tropical areas.

4. Research should be continued on fungicides and applications for textiles and cordage equipment to be used in tropical areas. Particular attention should be directed toward a search for fungicidal materials which are nontoxic to humans.

5. Further work should be encouraged to determine the mechanism of biological deterioration of natural fibers in order that the development of formulations to prevent this action could be approached with better understanding.

It is indeed gratifying that investigations on all of the above problems are among those which were represented in February 1946 in the research program of the Military Planning Division of the Office of the Quartermaster General.

10.3 RECOMMENDATIONS OF THE SUBCOMMITTEE ON ELECTRICAL AND ELECTRONIC EQUIPMENT

1. Investigations should be conducted on basic materials used in electronic equipment to determine their loss of properties with the absorption of water, wettability of surface, dimensional stability, and their susceptibility to fungal attack.

2. Investigations should be carried on to develop coating materials which will form a nonwettable surface on solid dielectrics.

3. The fungus-proofing of cotton for electrical uses should be investigated by its structural modification or by the addition of inhibitory chemicals to the cotton fibers in the thread-spinning process with the consideration that such treatments would be more durable and effective than the addition of fungicides to the wire finish.

4. The validity of test methods and standards used in specifications should be subjected to laboratory investigations and correlated with a condition of electrical stress and actual service life. The expected service life under humid tropical conditions of various components and assembled communications equipment should be determined.

5. Reports should be obtained from personnel who operated or reconditioned electronic communications equipment that was under conditions of excessive humidity, giving their commendations for exceptional good performance of specific equipments and components and desired improvements in design and engineering for use under such conditions.

6. Systematic maintenance practices for electronic

field equipment should be developed for use under conditions of excessive dampness.

7. An electrical measurement should be developed which will give a quantitative measure of degradation and be applied to electrical components which have been subjected to standard fungus tests as a required part of the procedure.

8. Liaison and coordination should be continued between the various branches of the Services that are investigating and engineering electronic communications equipment for use in tropical and arctic climates.

10.4 RECOMMENDATIONS OF THE SUBCOMMITTEE ON SYNTHETIC RESINS, PLASTICS, AND PLASTICIZERS

This subcommittee recommended that investigations on the deterioration of plastics be continued to provide information on the following broad problems:

1. The susceptibility of the basic components of plastic materials to fungus attack.
2. The effects of fungi and moisture on properties of plastics, mechanical as well as electrical.
3. The sterilization of plastic materials to eliminate contaminating organisms on control specimens in investigations of physical and electrical properties.
4. The incorporation of fungicides in plastic compositions to provide permanent protection during the service life of the products.

10.5 RECOMMENDATIONS OF THE SUBCOMMITTEE ON PHOTOGRAPHIC EQUIPMENT AND SUPPLIES

1. Investigation and background research should be continued in the study of component and constituent materials for photographic uses. This should include a study of the changes in all pertinent physical properties of such materials due to moisture, temperature, the action of fungi, and other deteriorating agents of the tropics.

2. The program should be carried on to coordinate the results of laboratory investigations and particularly test methods with actual deterioration in the field, with the end in view of providing a fundamental basis for comparing the deterioration produced in test chambers with the deterioration that occurs in the field under natural tropical conditions and ultimately standardizing the test methods used.

3. Data should be collected upon the performance of equipment under tropical conditions to establish the relationship between performance degradation and physical deterioration and to determine suitable operational ranges for all classes of photographic equipment and supplies.

4. Continued study should be devoted to obtaining the best possible coating materials and preservatives needed to insure adequate tropic-proofing and to prolong the service life of photographic matériel under field conditions.

5. A program should be initiated to investigate the nonnutrient, waterproof, substitute synthetic materials to replace gelatin in film and in filter manufacture. Included in this study should be the investigation of appropriate dyes to be used with new media and the improvement of the support materials themselves.

6. Further attention should be directed to improve and simplify the design and construction of cameras, etc., in order to allow for ready interchangeability of parts and to make field maintenance easier under tropical operating conditions. Provisions should be made to include protective and preservative features wherever necessary.

7. More efficient and expedient procedures and techniques to be used in the field maintenance problems under tropical conditions should be developed.

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CONTRACT NUMBERS, CONTRACTORS, AND SUBJECTS OF CONTRACTS

Contract Number	*Name and Address of Contractor*	*Subject*
OEMsr-905	The Trustees of the University of Pennsylvania Philadelphia, Pennsylvania	Tropical deterioration of optical glass, exposure tests on other equipment, and coordination of test methods.
OEMsr-871	The University of Pittsburgh Pittsburgh Pennsylvania	Exposure tests of instruments and equipment under tropical conditions.
OEMsr-1313	D. D. Berolzheimer 50 E. Forty-first Street, New York, N. Y.	Search of literature on tropical deterioration.
OEMsr-1356	The George Washington University Washington, D. C.	Information Center and surveys in the field of tropical deterioration.
OEMsr-1369	President and Fellows of Harvard College Cambridge, Massachusetts	Maintaining a Tropical Fungus Culture Collection.
OEMsr-1425	Bakelite Corporation New York, N. Y.	Tropical deterioration of plastics.
OEMsr-1479	The Johns Hopkins University Baltimore, Maryland	Deterioration of electrical insulating materials by molds and moisture.
OEMsr-1484	The Agricultural Experiment Station of the Alabama Polytechnic Institute Auburn, Alabama	Maintaining a Bacteria Culture Collection.
OEMsr-1438	Rensselaer Polytechnic Institute Troy, New York.	Fungus growth on hookup wire.

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Office of the Executive Secretary, OSRD, from the War or Navy Department through either the War Department Liaison Officer for NDRC or the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	*Subject*
AN-14	Prevention of deterioration of matériel under tropical conditions.
AN-14.1	Fungus growth on hookup wires. (Requested by the Signal Corps.)
AN-14.2	Deterioration of photographic and X-ray film due to fungus, insects and moisture. (Requested by Headquarters, Army Service Forces, Maintenance Division.)

INDEX

The subject indexes of all STR volumes are combined in a master index printed in a separate volume. For access to the index volume consult the Army or Navy Agency listed on the reverse of the half-title page.

TSDIN FORM 69 (13 MAR 47)

U.S. Office of Scientific Research and Development.

AUTHOR(S)

DIVISION: Materials (8)

SECTION: General Data (15)

CROSS REFERENCES: Climate - Effect on materials (23307); Electronic equipment - Tropical deterioration (31538); Instruments - Optical - Tropicalization (52257)

R-8-15-12

ATI- 12120

ORIG. AGENCY NUMBER

REVISION

AMER. TITLE: Tropical deterioration of equipment and materials

FORG'N. TITLE:

IS NOW AD200630

1.15.59

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	1946	91		

ABSTRACT

In tropical warfare, equipment and supplies are exposed to heavy rainfall and high relative humidity, which together introduce numerous problems relative to performance and serviceability. Activities concerned with fungi, isolated in studies of Panama, are reviewed. Deterioration of optical instruments, textiles, resins and plastics, photographic equipment, and electric and electronic equipment is discussed. At the time of the Japanese surrender, valuable preliminary results had been obtained from studies but none had reached completion.

ATI- 12121

REVISION (None)

ORIG. AGENCY NO. (None)

PUBLISHING AGENCY NO.

TITLE: Tropical Deterioration of Electric and Electronic Equipment

AUTHOR(S): (Not known)
ORIGINATING AGENCY: Office of Scientific Research and Development, NDRC
PUBLISHED BY: (Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
1946	Unclass.	U.S.	Eng.	34	(None)

ABSTRACT:

High and fluctuating temperatures and humidities result in the ingress of water vapor with subsequent condensation and deleterious effects in mechanical and electrical properties of materials. Fungi are also important agents of deterioration in electric and electronic equipment. Moisture retention by surface mold encourages corrosion of metal parts as do organic acids which are produced in the metabolic activity of fungi. Moldy surfaces dry because air diffusion is retarded. Prolonged exposure results in chemical breakdown of finishes and coverings.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

DIVISION: Electronics (3)
SECTION: Components (10)

SUBJECT HEADINGS: Electronic equipment - Tropical deterioration (31538)

26530

ATI SHEET NO.: R-3-10-33

ELECTRONICS (COMPONENTS)